SOUTH AFRICAN RAILWAYS

HANDBOOK

ON THE

STEAM LOCOMOTIVE

FOR ENGINEMEN AND
RUNNING SHED STAFF

1956

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SOUTH AFRICAN RAILWAYS

ACKNOWLEDGEMENT FORM

I, ……..…….
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NOTE

The official responsible for the distribution of the 'Handbook on the Steam Locomotive for Enginemen and Running Shed Staff' must see that an acknowledgement form is obtained from every servant receiving a copy of the Handbook. The completed acknowledgement forms must be submitted to the Staff Office of the System Manager.

HANDBOOK

ON THE

STEAM LOCOMOTIVE

FOR ENGINEMEN AND
RUNNING SHED STAFF

I. This handbook on the Steam Locomotive is issued principally for the guidance of enginemen and running shed staff, and it will be the duty of each servant concerned to make himself acquainted with and act in accordance with the contents thereof.

II. Every servant of the Administration affected by the instructions contained in this handbook must be supplied with, and produce when required, a copy thereof.

III. Supervising officers must satisfy themselves that a copy of 'The Handbook on the Steam Locomotive for Enginemen and Running Staff' has been issued to each member on the staff concerned coming under their jurisdiction. They must also take the necessary steps to assure themselves from time to time that the instructions therein contained are properly understood and acted upon.

D. H. C. du Plessis
General Manager
Johannesburg
1st August 1956

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SECTION 1

INTRODUCTORY & HISTORICAL: HEAT & COMBUSTION

INTRODUCTION

The object of this handbook is to give brief descriptions of the most important parts of (and fittings used on) steam locomotives on South African Railways, and to indicate their purpose and how they function. In addition, instructions are given on how to deal with the more common breakdowns.

The handbook is intended to be an introductory guide for footplate & running shed staff, and does not treat the whole subject of the steam locomotive in an exhaustive manner. The instructions given are in addition to (and must be read in conjunction) with those contained in the *Train Working Regulations, General Appendix, Local Appendices* and *Working Time Books*.

The staff should take every opportunity of examining parts of locomotives dismantled in running sheds, as this is the most satisfactory way of understanding how they work, and what they are intended to do.

HISTORICAL

The first commercially successful steam engine was a stationary pumping engine built in 1698 by Savery. Development was steady until James Watt, in 1763, produced the independent condenser, and later a number of other devices, which made the stationary steam engine a really useful machine.

While earlier attempts to construct steam road carriages had been made, the first locomotive to run on rails was built in 1802 by Richard Trevithick in Cornwall, England. In 1804 he built an improved locomotive, which hauled coal wagons on the Merthyr Tydvil Railway in South Wales, believed to be the oldest steam worked railway in the world. From then on, development of the steam locomotive was rapid, until in 1829 George Stephenson and his son Robert built the famous locomotive *Rocket,* which won a £500 prize offered by the Liverpool & Manchester Railway in England.

The 'Rocket' was fitted with a multi-tubular boiler, with a water jacketed firebox and a smokebox, and had two outside cylinders coupled to a single pair of driving wheels. The exhaust steam from the cylinders was lead to a blast pipe in the smokebox, to produce the necessary draught. The basic principles of the steam locomotive as used today were thus laid down in 1829, and except for developments in detail and in size, no fundamental changes have been made since then.

In South Africa a short railway was opened in June 1860, from the Point Docks to Durban, and in May 1861, the first portion of the railway from Cape Town to Wellington was opened. From then on railway development was rapid throughout the country, and in 1910, at the time of Union, the railways of the various colonies were amalgamated into the S.A.R., which now covers over 13,000 route miles.

HEAT & COMBUSTION

Heat may be regarded as a form of energy which can to some extent be converted into useful mechanical work. Heat is usually produced by the combustion of fuel, and in the case of the steam locomotive the fuels normally used are coal, oil and wood. On the S.A.R. coal is the only fuel of any importance, and it consists essentially of carbon, a number of complicated chemical compounds of hydrogen and carbon (known as hydrocarbons) and incombustible ash.

When substances combine with oxygen, heat is produced, and when the production of heat is very rapid, the reaction is usually called 'combustion', and the substance is said to 'burn'. While coals from different areas vary widely in composition, the general conditions of combustion of coal in a locomotive firebox are the same. The carbon burns on the grate, liberating great heat, and driving off the hydrocarbons as volatile or gassy matter, which burns with luminous flames above the grate. The oxygen necessary to support combustion comes from the air, which consists of approximately one-fifth oxygen and four-fifths other gases, mainly nitrogen, which play no part in combustion.

The result of supplying insufficient air will be to cause smoke, which consists mostly of unburned hydrocarbons, while if too much air is supplied, some of the heat of the fire will be uselessly absorbed in heating that portion of the air which is additional to that required for complete combustion.

One of the most convenient ways of converting heat into mechanical work is to use the heat to change water into steam, which in turn can be used in an engine. The water and steam are thus the means of transmitting the heat energy liberated by the combustion of the fuel to the engine, where useful work is produced.

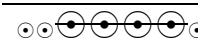
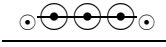
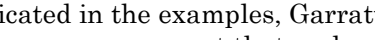
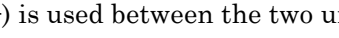
SECTION 2

CLASSIFICATION & WHEEL ARRANGEMENT

All locomotives on the S.A.R. are classified according to their type, and in general all engines of a particular class are interchangeable, although there are a few exceptions. The class is indicated on each locomotive by small figures, letters, or both, immediately below the running number on the cab number plates. The letter 'R' in the classification (e.g. 15AR) indicates that the engine concerned has been re-boilered with a *Standard Boiler*. The more modern locomotives, which were *built* with standard boilers, do not carry the letter 'R' in their classification.

The wheel arrangement of a locomotive is given by three figures in the case of a normal non-articulated engine. The first figure denotes the number of carrying wheels at the leading end, the second the number of coupled wheels, and the third the number of carrying wheels at the trailing end.

Some examples of various wheel arrangements are given below:

Arrangement	Type	Example
	4-6-0	Class 6
	4-6-2	Class 16DA
	4-8-0	Class 8
	4-8-2	Class 15F
	2-8-2	Class 11
	0-8-0	Class S
	4-6-2 + 2-6-4	Class GF
	2-6-2 + 2-6-2	Class NGG16

As indicated in the examples, Garratt articulated locomotives are described in a similar manner, except that each unit is dealt with separately, and a plus sign (+) is used between the two units. **Fig 1** also shows the arrangement.

SECTION 3

FRAME: WHEELS & BOXES: BOGIES: PONIES: BISSELS: SPRINGS & COMPENSATION

Plate frame. Bar frame. Cast steel frame. Horns. Shoes & wedges. Horn stays. Wheels & axles. Axle-boxes for coupled wheels, bogies, bissels & tenders. Roller bearing axle-boxes. Purpose of leading bogie. Details of bogie. Purpose of bissel. Details of bissel. Leading ponies. Springs. Compensation. Overhung & underhung springs.

FRAME ETC

The frame of a locomotive is the foundation to which the various parts are secured. Three types of frame are in use on the S.A.R., viz., the plate frame, the bar frame and the cast steel frame.

The plate frame consists essentially of two parallel steel plates secured together by a buffer beam at each end, and by various frame stretchers. Inside each buffer beam is a heavy casting known as the drag box, which carries the drawgear. Many plate frames are fitted near the rear end with a large casting called the bridle casting, which in effect widens the frame out so that the lower portion of the firebox can fit inside the frame.

Along each side of the frame are large slots, one opposite each coupled wheel, to which are secured the horns, in which the axle-boxes for the coupled wheels are fitted.

The cylinders and the smokebox saddle are bolted to the frame near the front end, and underneath the saddle is the top bogie centre casting the pivot on which the bogie can rotate.

Fig 2 shows an example of a plate frame.

The bar frame consists of two steel slabs usually from 3 to 4 inches thick, slotted out for lightness. As with the plate frame, a buffer beam and a drag box casting are fitted at each end, but a bridle casting at the rear end is not often used, as it is possible to sweep a bar frame low enough to fit underneath the firebox. Several frame stretchers are fitted.

The slots for the coupled wheel axle-boxes exist on each side, as on the plate frame, but separate horns are not necessary as the frame itself is thick enough to form an adequate bearing surface.

The cylinders, smokebox saddle, top bogie centre, etc., are bolted to the frame in a manner similar to that used on a plate frame.

On the S.A.R., most modern locomotives, and some of the older ones, have bar frames, as there are certain advantages in this type of frame when applied to South African conditions. The most important of these are (1) that the lower portion of the firebox is easily accessible for washing out and repair, (2) that bar frames are very rigid transversely, thus largely eliminating any bending sideways on severely curved track, (3) that springs and compensating gear can be arranged in convenient and accessible positions, and (4) that very few frame bolts and no rivets, which are likely to work loose, are necessary.

The two main disadvantages of the bar frame, viz., its weakness vertically and its weakness near the front end, can be simply overcome by fitting deflection plates, commonly known as boiler barrel supports, between the boiler barrel and the top of the frame, and diagonal stays from the smokebox to the front end of the frame. In this way the boiler is used to stiffen the frame.

Fig 3 shows an example of a bar frame.

The cast steel locomotive bed is a recent modification of the bar frame, developed in the United States. In general design it is very similar to the bar frame, except that the buffer beams, drag box castings, frame stretchers and cylinders (complete with steam chests and smokebox saddle) are all cast in one piece with the two main frame members. This reduces the number of bolts required to a small quantity and has the further advantage, particularly on large locomotives, that the cylinders cannot become loose. There are certain other advantages over the normal bar frame, but as these are mainly finer points of design, they will not be detailed here.

Fig 4 shows an example of a cast-steel frame.

The gaps in the frame for the reception of the coupled wheel axle-boxes are fitted with two separate wearing pieces, so as to avoid damage to the horn blocks in the case of a plate frame engine, or the frame itself in the case of a bar frame engine. One wearing piece is the horn shoe, which consists of a flat steel plate, with a small flange on each vertical edge, fitting tightly over one side of the horn, and bolted firmly to it. The other is the wedge which is a tapered steel block fitting snugly against the opposite side of the horn. By lifting the wedge, any reasonable amount of wear on the side faces of the axle-box may be taken up, which prevents the axle-box from knocking in the horns when the engine is running. The wedge is held to the horn by a securing bolt which passes through a vertical slot in the horn, thus allowing for adjustment

of the wedge, and this adjustment is obtained by a long bolt passing through the horn stay, and locked by suitable nuts.

It will be seen from the sketch, **Fig 5**, that one side of the horn is tapered to receive the wedge, while the other side is vertical. The inner faces of the horn shoes and the wedges form parallel surfaces between which the axle-boxes may slide up and down freely, as they are required to do by the irregularities on the upper surfaces of the rails.

The horn gaps are weak spots in the frame, and in order to prevent bending (and probably breaking) of the frame, horn stays are bolted tightly across the bottom of the gap, after the wheels and boxes are in position. It is important that all horn stays be kept tight, otherwise cracking of the frame is almost bound to occur.

WHEELS ETC

All wheels used on locomotives, passenger and goods stock, are made up in pairs, the two wheels being firmly secured to the axle by pressing on, in addition to which locomotive coupled wheels are keyed to the axle to prevent any possibility of movement.

Pairs of wheels are held in position, and the weight of the engine or vehicles is transmitted to them by means of axle-boxes. These vary considerably in design to suit the particular job they are required to do, but in all cases they fit over specially machined portions of the axle called the journals.

On a locomotive, the leading bogie or pony axle-boxes and the coupled wheel axle-boxes are usually fitted between the wheels, while the bissel and the tender axle-boxes are usually fitted outside the wheels. There are certain exceptions to this arrangement, but they are not of great importance. The usual design of coupled wheel axle-box consists of a heavy bronze casting of inverted 'U' form, with a wide groove machined on each side to fit between the horns. This allows the axle-box to move up and down between the horns, but all other movement (except rotation of the axle) is prevented, and the axle with the two wheels attached is therefore firmly located in the engine frame. The bottom of the axle-box, underneath the axle, is closed by means of a keep, which holds either the waste packing in the case of an oil lubricated axle-box, or the grease cellar in the case of a grease lubricated axle-box.

Fig 6 shows an axle-box in position.

To prevent the coupled wheels from moving sideways, i.e. at right angles to the track, the axle-boxes are fitted close up to the bosses of the wheels, and specially prepared rubbing surfaces are provided on both the wheels and the

axle-boxes to take the forces acting at right angles to the length of the engine, which are developed when the locomotive is on curved track.

Leading bogie axle-boxes are smaller, but normally are of the same general design as coupled wheel axle-boxes. Except in the case of some roller bearing axle-boxes, they are always lubricated with oil.

The normal practice is for oil-lubricated bogie, pony and coupled wheel axle-boxes to be made with slots or pockets in the crown to hold white metal where they rest on the axle, and on the boss face where they come in contact with the wheel. Grease lubricated coupled wheel axle-boxes are not provided with white metal in the crown, although many have white metal on the boss wearing faces.

Most bissel axle-boxes are bolted rigidly to the bissel frame, and are essentially receptacles for a loose bearing and for waste packing, unless they are of the roller bearing variety. The loose bearing is made of bronze, and is lined with white metal on the surface in contact with the journal.

Tender axle-boxes are somewhat similar to the bissel axle-boxes, except that they are not normally secured to the tender bogie frame, but fit between horns, and are free to move up and down. The loose bearing, which is easily renewed when necessary, is a regular feature of axle-boxes arranged outside the wheels.

Up to the present, roller bearing axle-boxes have been used on S.A.Railways locomotives only on the leading bogie, bissel and tender wheels. The axle-boxes themselves are in general similar externally to the plain bearing axle-boxes used in similar positions. The lubrication of the roller bearings is the responsibility of the shed staff, and the driver is expected only to see that the boxes work freely in the horns, where provided, and to lubricate the horn faces. The internal lubrication of roller bearing axle-boxes is covered by special instructions issued by the Chief Mechanical Engineer.

The leading bogie consists of a small independent frame supported on four wheels, and so arranged that it can rotate to a limited extent with respect to the engine frame, as well as move at right angles to the engine frame through a small distance in either direction. The bogie is provided to assist in guiding the engine round curves, to reduce pitching and side to side oscillation on straight track, and to support the leading end of the engine.

It must be understood that the rigid wheel base of a locomotive is limited by the sharpest curve in the track. A very long rigid wheel base would cause the wheel flanges to bind on a sharp curve, and possibly to climb out and derail. If a large boiler is desirable from the point of view of steam supply, some

additional wheels besides the coupled wheels, which form the rigid wheel base, will probably be necessary. Apart from its guiding and steadying properties, mentioned above, a leading bogie provides the additional wheels needed, and is very commonly used on locomotives.

With a few exceptions, the normal arrangement of the leading bogie on the S.A.R. is as follows:

The top bogie centre or pivot is bolted firmly to the bottom of the smokebox saddle or to a separate casting attached to the frames. This fits into the bottom centre casting, which is in the form of a cup, and forms an oil bath. When in position the two centre castings are prevented from separating accidentally by means of a clamp.

The bottom centre casting fits between two parallel cross stretchers, attached to the bogie frame, which permit the centre casting to move sideways, but not longitudinally. It is supported by two long pins, at the bottom, which pass through the lower eyes of four swing links, which in turn are secured at their upper ends by four short pins to the cross stretchers, which (as previously stated) are attached to the bogie frame.

The two side frame members rest at their centres on the buckles of two inverted semi-elliptical springs, one on each side, which in turn are connected at their ends by spring hangers to two equalizing beams. These beams rest in recesses formed in the tops of the bogie axle-boxes, which work between horns bolted to the bogie frame.

On some of the more modern engines the control of the side movement of the bogie is by means of the swing links only, but on a great many bogies two side control springs are fitted in addition to the wing links. These springs are usually of the semi-elliptical type coupled together by means of links at their ends and fitted into a cradle bolted to the bogie frame below the bottom centre casting, to which a small bracket carrying a roller is secured. This roller presses on the buckle of one or other of the springs when the bottom bogie centre moves sideways in relation to the bogie frame. This has a considerable guiding action on the main engine frame, and also tends to hold the main frame in line with the bogie on straight track.

Fig 7 and **Fig 8** show the leading bogie and leading bogie side control arrangement respectively.

Many locomotives are fitted with a bissel at the rear end, which consists of a small frame supported on one pair of wheels. This is provided to carry a portion of the weight of a large wide firebox, particularly when it would not be possible to fit a pair of coupled wheels underneath it. The bissel also serves to

steady the rear end of the locomotive, and to prevent it from swinging over too far on sharp curves.

The design of bissels for different classes of locomotive varies in detail, but in general the frame is provided with a triangular extension running forward, and secured at its apex to a king pin attached rigidly to the main engine frame. This arrangement ensures that the bissel will move sideways in a circular path, as indicated in the sketch, **Fig 9**.

The axle-boxes are sometimes bolted to the bissel frame, and sometimes work between horns in this frame. The movement of the bissel to either side is limited by coil springs, enclosed in a box which is bolted to the engine frame. Plungers or 'dumbells' are fitted between the control springs and the rear end of the bissel frame, thus giving the required control and steadying effect.

The weight of the rear end of the locomotive is transmitted to the bissel through two semi-elliptical springs, one on each side. The spring hangers are attached at the rear end to brackets on the engine frame and at the front end to compensating beams, while the spring buckles test on saddles so arranged that they can only move in a vertical direction. From the saddles the weight is transmitted through sliding shoes to friction plates on the top of the bissel axle-boxes, and thence to the axle and the wheels.

Fig 10 and **Fig 11** show the bissel side control arrangement and the bissel bearing spring rigging respectively.

Some locomotives, mainly Garratts, are provided with a two-wheeled leading pony instead of a bogie. These ponies are in most cases similar in design to bissels except that the axle-boxes are usually inside the wheels. They serve the same purpose as the bogie in guiding the engine on curves and in reducing oscillation on straight track.

On a locomotive, as on all other railway vehicles, all wheels are provided with springs, in order that the locomotive may run reasonably smoothly on the track. On the S.A.R., with very few exceptions, the springs used are of the laminated semi-elliptical type, and apart from the leading bogies, each axle-box is normally provided with a separate spring. On the leading bogie there is only one spring on each side, and the same applies to most tender bogies.

With the exception of a few obsolete classes, all locomotives on the S.A.R. are fitted with compensated spring gear. In this arrangement, all the springs of the group which are compensated are connected to compensating beams, which are secured to the engine frame by means of pins. The outer ends of the first and the last springs of the group are connected to fixed brackets on the frame. The purpose of compensated spring gear is to prevent the weight on

any one wheel from increasing or decreasing by more than a small amount, as the compensation transfers weight either to or from the other wheels in the group, thus maintaining a reasonably constant weight on each wheel, even on irregular track. The working of the compensating gear can easily be seen when an engine is moved slowly over points or other track irregularities.

Fig 12 and **Fig 13** show two of the most usual methods of compensating employed on the S.A.R.

Coupled wheel springs are fitted either above or below the axle-boxes, the former method being standard on all the more modern engines. When fitted above the axle-box, the weight is transmitted by means of a saddle of inverted 'U' shape, which fits over the top frame member. The two lower edges fit into recesses formed in the top of the axle-box, while the upper surface fits against the underside of the spring buckle. The ends of the spring are attached to the compensating beams by means of spring hangers. These are secured to the beams by pins, while at the upper end they pass through slots in the spring and are secured by large cotters.

When springs are fitted below the axle-boxes, the spring buckle is made with two heavy lugs on the upper side, and a large pin passes through holes in these lugs and in the axle-box keep.

SECTION 4

BOILER: SUPERHEATER: DRAUGHT APPLIANCES: SPARK ARRESTORS: BOILER MOUNTS: MECHANICAL STOKERS
Principal parts of boiler. Draught arrangements. Stays. Tubes. Arch tubes. Thermic syphons. Boiler insulation. Superheated steam. Advantages of superheating. Superheater header & elements. Securing of the boiler to the frame. Grates. Ashpan. Details of draught arrangements. Leakage of air or steam into smokebox. Steam blower. Secondary air. Brick arch. Spark arrestors. Boiler mounts. Injectors. Clack boxes. Water gauges. Safety valves: Ramsbottom & Ross Pop. Fusible plugs. Pressure gauge. Blowdown cock. Regulators: double beat & multiple valve. Steam turret. Scum cock. Washout plugs. Grate shaking donkey. Steam heating. Headlight turbine & generator. Mechanical stoker. Water separators.

THE BOILER

The locomotive boiler is designed to produce a large quantity of steam in a comparatively small space, and a considerable proportion of the heat produced in the fire is not used. In other words, the boiler is not very efficient. While boilers much more efficient than the locomotive type can be built, it would not be possible for practical reasons to fit them to a locomotive, so that a lower efficiency must be accepted to obtain the most suitable type.

The locomotive boiler always consists essentially of the following parts:

- *The inner firebox,* made of steel or of copper plates, or partly of copper and partly of steel
- *The outer firebox,* made of steel plates
- *The barrel,* made of steel plates
- *The tubes,* made of steel
- *The smokebox,* made of steel plates

The plates are normally joined together by means of rivets, but in the case of a steel inner firebox, welding is sometimes used instead of riveting, and the modern tendency is to increase the use of welding.

Fig 14 refers to the general construction of the boiler. Coal is introduced through the firehole **P**, which is provided with a door, not shown. The coal is held on the grate, where it burns, and the flames and hot gases are deflected backwards by the firebrick arch **D**, thus distributing the heat over the whole of the inner surface of the inner firebox. The hot gases then pass through the tubes **F** and **G** to the smokebox.

The draught is produced by leading the exhaust steam from the cylinders through the blast pipe **M**, where a strong jet is produced, which entrains the gases in the smoke box and discharges them through the chimney **N**. The ejector action of the exhaust steam in the smokebox produces a partial vacuum there, and the only entrance for the air is through the ashpan, the grate, the fire, the firebox and the tubes.

The inner and outer firebox plates are secured together by a large number of screwed stays, thus preventing the plates from bulging under the pressure existing in the boiler. The water spaces all round the inner firebox prevent the plates from becoming overheated, and a large amount of steam is produced in this area, which is the hottest part of the boiler.

The details indicated by letters are as follows:

A	Firebox tube plate	**B**	Firebox crown
C	Firebox inner back plate	**D**	Brick arch
E	Arch tubes	**F**	Superheater flue tubes
G	Boiler tubes	**H**	Dome
J	Internal dry steam pipe	**K**	Superheater header
L	Superheater elements	**M**	Blast pipe
N	Chimney	**O**	Smokebox door
P	Firehole	**Q**	Smokebox tube plate
R	Outer throat plate	**S**	Firebox outer back plate

The tubes and flue tubes are secured in the smokebox tube plate by expanding, and in the firebox tube plate by expanding and beading. Where a steel firebox tube plate is used, the tubes are further secured by a light run of welding round the edge of the beading, but this is never done in the case of a copper tube plate. **Fig 15** shows details of the way the tubes are secured.

In this connection, refer to the following sketches:

Fig 16 Firebox stay arrangement
Fig 17 Rigid space stay
Fig 18 Rigid crown stay
Fig 19 Flexible space stay
Fig 20 Flexible crown stay
Fig 21 Palm stay
Fig 22 Detail of cross stay
Fig 23 Gusset stay

The circulation of the water in the boiler is very important, as the faster the water circulates the more readily is the heat of the fire absorbed by the water. As it is not possible to use pumps to give a rapid forced circulation of water in a locomotive boiler, reliance must be placed on natural circulation, and two devices are in use to improve this natural circulation.

They are:

(1) Arch tubes
(2) Thermic syphons

(1) Arch tubes are fitted to most of the larger boilers on the S.A.R. and are connected to the lower portion of the tube plate in the throat area, and slope upwards from there to the inner back plate above the firehole. Increased firebox heating surface is thus provided, and further, the water in the front (throat) water space is caused to move rapidly through the arch tubes to the upper portion of the back water space. The arch tubes also serve to support the brick arch. See **Fig 24** for details.

(2) Thermic syphons serve much the same purpose as arch tubes, but deliver water to the crown of the firebox, instead of to the back water space. They also provide a much larger heating surface than do arch tubes.

Certain large boilers on the S.A.R. are equipped with two thermic syphons, and in order to provide the necessary support for the brick arch, arch tubes are also used. **Fig 25** shows details of the thermic syphon.

To prevent loss of heat from the outside surface of the boiler, an insulating covering is provided, which usually consists of asbestos blankets. These blankets are covered by thin steel sheets, known as lagging sheets, which serve to protect the blankets and to give the boiler a finished appearance.

SUPERHEATED STEAM

If steam from the steam space of the boiler is passed through tubes heated by the firebox gases, the first thing that happens is that any drops of water carried over with the steam are evaporated, and the steam is thus *dried.* After that the temperature of the steam is raised above the normal boiler temperature (which corresponds to the pressure) and *superheated* steam results. In a locomotive boiler superheating does not raise the *pressure* of the steam, as while the regulator is open there is free communication between the superheater and the boiler. Superheating does, however, increase the *volume* of the steam.

Almost all modem locomotives use superheated steam, as the following advantages are obtained:

(1) Superheated steam contains more heat energy than saturated steam.
(2) Cylinder condensation is greatly reduced, if not entirely eliminated.
(3) A somewhat smaller *weight* of steam is taken from the boiler for each stroke of the piston, and therefore less water and coal are consumed than when using saturated steam.

The locomotive superheater consists of a cast iron header containing two main compartments, each with a number of branch passages. One compartment, with its branches, contains saturated steam from the boiler, while the other, with its branches, contains superheated steam ready for delivery to the cylinders. The superheating of the steam is carried out in 'elements' connected to the header and consisting of small tubes making a double loop inside the flue tubes running through the upper portion of the boiler barrel. The elements are heated directly by the hot gases passing through the flue tubes from the firebox to the smokebox. The header is placed in the smokebox, and secured to the smokebox tube plate, in such a manner that the internal main dry steam pipe is coupled direct into the main saturated steam compartment. On the S.A.R., it is the normal practice for the regulator to control the supply of *saturated* steam, so that while the regulator is closed the elements are empty. This applies whether the regulator is situated in the dome, as in the older boilers, or incorporated in the superheater header ('multiple valve' regulator) as in more modern boilers.

Fig 26 shows a superheater header.

The method of securing the boiler to the frame of the locomotive is standard throughout the world. The smokebox is bolted firmly to a saddle between the frames, and the firebox is carried on brackets or expansion plates resting on the rear end of the frames. This allows for expansion and contraction of the boiler, while ensuring that there is no movement at the smokebox end where the steam pipes and blast pipe are situated. The expansion brackets are fitted with clamps so arranged that the boiler cannot lift, but is permitted to slide freely longitudinally. On certain large engines, the expansion brackets are replaced by flexible plates fixed across the rear end of the frame, and fastened to the firebox. The amount that a locomotive boiler expands from cold to full working pressure and temperature is about ½ inch for each 20 feet of length.

The grate on which the coal is burnt consists of a series of cast iron sections, most of which are arranged to rock under the action of a hand lever or a small steam cylinder, so as to shake ashes out of the fire. In addition to the rocking grates, drop grates are fitted, usually at the front end of the firebox only, through which clinker may be cleared or the fire dropped when necessary. It is usual to fit a row of fixed grates or 'dummy bars' next to the tube plate, and immediately ahead of the drop grates. Two types of grate sections are used, the finger bar type and the perforated or pinhole type.

Fig 27 and **Fig 28** show the two types and how they are coupled.

Underneath the grate is the ashpan, made of steel plates, which on the older engines is fixed to the underside of the firebox foundation ring. On more modern engines the ashpan is carried on the main frames, a few inches clear

of the bottom of the foundation ring. The ashpan is provided to collect ashes, clinker and burning coal falling from the grate, and is equipped at the bottom with sliding doors, for emptying at suitable spots. Cooler pipes, fed with water from the injectors, run the full length of the ashpan at each side, and when the fire is being cleaned it is essential to use the coolers to quench the hot ashes and burning coal, and to prevent serious damage to the ashpan and to the track.

In order to avoid setting fire to wooden sleepers, grass or crops alongside the line, the ashpan slides should he opened only at authorized ash dropping points, and when the ashpan has been cleared the slides should immediately be closed and kept in that position. This is most important.

In order to produce the large amount of steam required, the locomotive boiler has to be fed with coal a great deal faster than is necessary in a stationary boiler, and to burn this coal as fast as it is fed, a large volume of air must pass through the fire bed. For this reason a strong draught is required, and moreover a draught which is automatically varied according to the amount of steam taken from the boiler is highly desirable. This is accomplished by using exhaust steam from the cylinders to produce the draught by ejector action.

The exhaust steam from both cylinders is lead by means of passages in the smokebox saddle to a single blast pipe, which is fitted with a nozzle usually called the blast pipe cap. This causes the exhaust steam to rush upwards at a high speed, and to entrain a considerable quantity of the gases in the smokebox and eject them through the chimney. To assist in directing the smokebox gases into the chimney, and to make the chimney as long as possible, a petticoat pipe made with a bellmouth at the bottom is fitted inside the smokebox below the external chimney. **Fig 29** shows the arrangement.

The ejector action of the jet of exhaust steam passing through the petticoat and chimney causes a partial vacuum to be formed in the smokebox. Provided the smokebox door is tight and there are no other leaks, the only way this partial vacuum can be destroyed, except through the chimney, is for air to travel up through the grate and the fire, and then through the firebox and the tubes. At reasonably high speeds, and provided the jet of exhaust steam just fills the throat of the petticoat, very little if any air enters the smokebox through the chimney.

The harder the engine is worked, the greater will be the demand for steam from the boiler, and also the greater will be the quantity of exhaust steam passing through the blast pipe. It will therefore be seen that if the blast pipe, the blast pipe cap, the chimney and the petticoat are correctly designed and properly fitted, the draught will be automatically varied according to the amount of steam taken from the boiler.

The smokebox acts as a reservoir for the hot gases coming from the fire, and if it is big enough also tends to maintain the vacuum between successive exhaust beats. A fairly long chimney and petticoat also help to do this, as at reasonably high speeds the last of the exhaust steam and entrained gases from one beat are barely clear of the top of the chimney before the jet from the next beat enters the throat of the petticoat.

It will be seen that, except for the chimney opening, the smokebox must be airtight, otherwise the vacuum will not be high enough to maintain a proper draught on the fire. Any leakage of high pressure steam inside the smokebox, from blowing steam pipe joints or superheater elements will also tend to destroy the vacuum, as the steam expands greatly on escaping into the smokebox. In this way a steam leak may prevent the boiler from steaming properly even though the quantity of steam lost through the leak may be quite small. If a leak of similar size occurred outside the smokebox the steaming of the boiler would probably not be affected at all.

In order to provide a draught when the regulator is not open, a steam blower is provided. This consists of a hollow ring formed in the top of the blast pipe cap with a number of small holes drilled so as to direct the steam into the petticoat. Steam is supplied from the boiler through a valve operated from the footplate. The blower should be operated with discretion, as excessive use of this fitting can (and often does) cause great damage to the firebox plates and the tubes.

While the main supply of air to the fire comes from the underside of the grate, a certain amount of air must be admitted over the top of the fire bed to ensure that sufficient oxygen is present to complete the combustion of the hydro-carbons driven off from the coal (see **Section 1**). This secondary air is supplied through the firehole door which is left slightly open for the purpose.

Fig 30 shows the direction of the gas and air currents inside the firebox and in relation to the brick arch.

To prevent large sparks being thrown out of the chimney, spark arrestors are always fitted in the smokebox. The standard design used on nearly all S.A.R. locomotives consists of a diaphragm plate fitted more or less vertically right across the smokebox, a table plate fitted horizontally just below or sometimes a short distance above the blast pipe cap, the perforated or wiremesh plates, and in many cases a deflector plate.

Fig 31 shows the arrangement of the spark arrestor.

The diaphragm plate helps to break up the particles of char drawn through the tubes by the draught, and also distributes the draught evenly over the

whole bank of tubes. All the char is thrown to the bottom of the smokebox, and in order to provide a strong enough current of gas to prevent the char accumulating, the deflector plate is fitted under the table plate. The only passage for the gases and finely divided char to the chimney is through the perforated or wiremesh plates, which have slots in them small enough to prevent the passage of sparks which might cause fires.

It is essential that all the plates, solid as well as perforated or wiremesh, fit closely against the sides of the smokebox and against one another, so that no openings are left through which large sparks can be drawn. Further, the openings in the perforated or wiremesh plates must be kept clean, so that the draught is not restricted.

If properly designed and fitted, this type of spark arrestor will keep the smokebox reasonably clean, and no great accumulation of ash and char should occur even on a long run.

BOILER MOUNTS

All boilers must by law be equipped with certain fittings to ensure as far as possible that they are worked safely and will not explode. Certain other fittings are also regularly used on the S.A.R. All of these fittings, compulsory and otherwise, are termed 'boiler mounts'.

The compulsory fittings consist of the following:

1. two separate devices for feeding the boiler with water;
2. a non-return valve and a stop cock where each feed water delivery pipe enters the boiler;
3. two separate devices for showing the true level of the water inside the boiler;
4. two or more safety valves;
5. a low water alarm device, consisting of fusible plugs or other audible warning;
6. pressure gauge;
7. blowdown cock;
8. boiler test plate.

The most important of the other boiler mounts used on the S.A.R. are:

9. regulator;
10. steam turret;
11. blower;
12. scum cock;
13. whistle.

1

The only devices used on the S.A.R. for feeding the boiler with water are injectors, two of which are fitted to every locomotive.

In principle the injector consists of a casing containing three cones, in line with one another, and fitted with connections for the supply of steam and water, for delivery of the water to the boiler, and for overflow of surplus water or steam.

Fig 32 shows the following arrangement:

Steam from the boiler flows through the steam cone **A** in which its pressure is reduced, and its velocity is increased to a high figure. Around the open end of the steam cone **A** there is a space **B** into which the water enters. The steam and water mix in the combining cone **C**, where steam condenses, imparting a high velocity to the water, which is now hot. The jet of hot water jumps the overflow gap at **O**, which is provided to allow water or steam to escape while the injector is being started, and enters the delivery cone **D**, where the velocity energy of the water is converted into pressure sufficiently high to overcome the pressure in the boiler.

As there must be a more or less definite relationship between the quantities of steam and water entering the injector to allow it to work properly, valves are provided on both the steam and the water connections, and the overflow is necessary to allow excess water or steam to escape until the valves are correctly adjusted.

Since one of the serious difficulties experienced with the simple injector is its liability to 'kick off' as a result of vibration and consequent disturbance of the jet of water crossing the overflow gap, modifications have been introduced to avoid this as far as possible, and to make the injector capable of restarting automatically when it does kick off.

In the standard type of injector most commonly used on the S.A.R., the automatic restarting feature consists of making a portion of the combining cone movable. This portion is usually known as the 'suction cone'.

Fig 33 shows the action of the injector and is described as follows:

The steam enters the steam cone from the injector steam valve, and emerges from the cone at a very high speed, but at a low pressure, where it meets the water, previously turned on, in the combining cone.

The suction cone at this stage is clear of the combining cone, and is resting against the end of the delivery cone. The steam is condensed by the cold water, and a partial vacuum is created in the combining cone and particularly in the space marked **A**. Atmospheric pressure in the overflow pipe fills the overflow space and forces the suction cone on to its seat against the lip of the combining cone, and the injector then works correctly. The space marked **B** is in constant communication with the overflow, past the guide vanes formed on the outside of the suction cone.

Fig 34 shows that the guide vanes are 'twisted', thus giving rise to the name 'twist cone' which is sometimes used. It must be clearly understood that the suction cone does not rotate, as the jet passes through it, not round it. The vanes are provided to keep the suction cone in proper alignment with the delivery cone, and to allow communication with the overflow, and the twist is given to the vanes to prevent them from wearing grooves in the guide portion of the delivery cone.

The high speed jet of hot water leaving the suction cone enters the delivery cone, where its pressure is increased to overcome the boiler pressure, as previously described.

Any disturbance in the supply of steam or water, or in the jet of hot water, will destroy the vacuum in the space marked **A**, and will allow the suction cone to drop, thus opening the overflow wide, and relieving the pressure. The injector should then start again automatically, as soon as the necessary vacuum is established to reseat the suction cone.

2

Water from the injectors passes through the delivery pipes to the clack box, in which are situated the non-return valves and the stop cocks required by law. The most usual form of clack box is fitted on the top of the barrel, near the smokebox, and consists of a brass casting containing two separate non-return valves or clack valves, and two separate stop cocks. The clack valves are necessary to prevent steam from the boiler from blowing back through the injector delivery pipe, and stop cocks are provided to shut off communication with the boiler in case the clack should stick open or require repairs.

Fig 35 shows the usual form of clack box used on the S.A.R.

On some of the largest locomotives two separate clack boxes are used, near the top of the boiler barrel, as the usual double clack box mounted right on top of the barrel would be higher above rail level than is allowed by the loading gauge.

Under the clack box there is a distributing nozzle, which delivers the water on to the injector baffles fitted inside the boiler barrel. These ensure that the water is thoroughly heated before reaching the hot metal parts of the boiler, and also assist in depositing any scale-forming salts in the feed water as a fine mud, which is easily washed out.

While the feed water delivered by the injectors is hot, it is not nearly as hot as the water in the boiler, and therefore the feed water should enter the boiler as far away from the hot firebox as possible, to prevent sudden contraction of the firebox plates. This is why the clack box is placed near the smokebox.

3

The water level gauges used on the S.A.R. are of a standard pattern, and two of them are fitted to the back plate of every locomotive boiler. Each water gauge consists of two special cocks, one connected to the steam space, and one to the water space of the boiler. The cocks are connected together by means of a strong glass tube, which shows the true level of the water in the boiler. A test cock is fitted below the bottom of the glass tube, for testing the water level, and for blowing steam through the glass for cleaning purposes. On the front and sides of the gauge glass (as seen from the footplate) there is a protector consisting of three pieces of thick glass held in a frame. This is called the gauge glass protector and is a most necessary fitting to prevent injury to the engine crew should a gauge glass break. It also serves to protect the gauge class against bumps and cold draughts. The drawing, **Fig 36**, shows the construction of the water gauge.

It will be seen that the water cock contains a small ball valve, which is so arranged that it will close automatically if the gauge glass should break, and so prevent hot water and steam from blowing into the cab. The steam cock contains a reducing valve with a small hole drilled through it so as to direct the steam into the centre of the gauge glass and thus prevent it from being worn away, and also to restrict the flow of steam if the gauge glass should break.

4

Safety valves are provided on boilers to prevent the pressure from rising above the authorized working pressure. Two types are in use on the S.A.R., the Ramsbottom type and the Ross 'Pop' type, and they are normally fitted to the top of the firebox wrapper plate. On the largest modern boilers the safety valves are placed slightly to each side of the centre line, so that they will not project too high and foul the loading gauge.

Fig 37 shows that the Ramsbottom safety valve consists of a hollow cast iron base, in direct communication with the boiler, and on this base are mounted

two hollow brass pillars. A valve is fitted to the top of each pillar, and a lever is arranged over the top of the two valves. The necessary load is applied to the two valves by means of a strong coil spring, anchored at the bottom between the valve pillars, and attached to the lever at the top. The tension of the spring can be adjusted by means of nuts, and when the valves are correctly set, a seal is placed on the adjusting nuts. In no circumstances may any unauthorized person interfere with the adjustment of safety valves, and no locomotive should ever be allowed to leave the running shed unless the valves are properly sealed.

A slotted link is provided inside the spring, so that the valves will be prevented from flying off if the spring should break. All normal movement of the valves is allowed for by the slot in the link.

The action of the safety valve is as follows. When the boiler pressure rises, the steam presses against the underside of both the valves. This force is resisted by the spring, until the authorized working pressure is reached, when the whole system is just in balance. Any further rise in boiler pressure will result in the force on the two valves being greater than the force exerted by the spring, and the valves will therefore lift and allow the steam to escape until the pressure drops sufficiently for the spring to overcome the force acting underneath the valves, and the valves will close.

The disadvantages of the Ramsbottom valve are that the boiler pressure tends to rise slightly above the authorized working pressure before the valves open fully, and further that the valves do not close completely until the pressure has fallen to about 5 lb per square inch below the authorized working pressure. This causes an unnecessary loss of steam.

The Ross Pop safety valve is more sensitive, and two, three or four are fitted to all the more modern locomotive boilers. The design varies slightly in detail, but the principle is the same in all instances.

Fig 38 shows the construction of the valve. The spring acts on the spindle, which rests on the valve. When the steam reaches the authorized working pressure it lifts the valve against the force of the spring. The steam strikes the lip of the valve and passes round it and through the small holes just inside the lip. This causes the ‘pop’ action.

The steam then flows up the casing until it strikes the top cap, which is attached to the spindle. Although the steam is now at a lower pressure, and some of it is flowing through the holes in the top cap, as well as round it and through the slots in the edge of the cap, and out through the holes in the top of the casing, there is a considerable force acting upwards on the cap. This helps to lift the spindle against the action of the spring, and therefore opens

the valve wide, which prevents the boiler pressure rising unduly above the working pressure.

Above the cap is a plate with holes drilled in it, and so arranged that, by turning it, the number of holes open in the top cap can be varied. If there is a large number of holes open, the pressure exerted on the cap by the escaping steam is low and the valve closes quickly. The fewer the number of holes left open, the greater is the pressure exerted on the cap and the longer the valve remains upon. Thus, a given quantity of surplus steam can escape quickly or slowly, depending on the number of holes open, but it must be clearly understood that a greater quantity of surplus steam will keep the valve open longer than a smaller quantity. By this means the loss of boiler pressure when the safety valves are open can be regulated, and further, the valve is prevented from vibrating up and down when the pressure just reaches blowing off point.

Enginemen must remember that they are not permitted to adjust or otherwise interfere with safety valves. Any defects noticed should be promptly booked, and if serious, should be reported on arrival at a locomotive depot.

5

Low water alarm devices used on locomotive boilers consist of fusible plugs screwed into the crown sheet of the inner firebox. In small boilers two are used, one near the front and one near the back of the crown, approximately on the longitudinal centre line. In larger boilers three plugs are fitted, two near the front and one near the back of the crown. The two near the front are placed towards the sides, to protect the firebox when the engine is rounding curves or standing on heavily banked track. **Fig 39** shows the construction of the fusible plugs and the way they are screwed into the crown sheet.

When there is sufficient water in the boiler, the water will prevent the lead in the plug from fusing, as the melting point of lead is 621° F. while the temperature of boiling water at 210 lb per square inch is 392° F. If however the water level becomes dangerously low, the top of the plug will become uncovered and, as steam is of little use as a cooling agent, the heat of the fire will melt the lead and the steam will blow into the firebox. This will probably extinguish a low fire, when the engine is stabled, but would not have much effect on a bright fire on the road. It is essential that the fire be thrown out as quickly as possible if a fusible plug should drop, and the prompt use of both injectors may avoid serious damage to the fire box.

6

All boilers must be equipped with a pressure gauge which will give a continuous reading of the pressure inside the boiler. The type of gauge always used on the S.A.R. is shown in the sketch, **Fig 40**.

The curved spring tube **B** is the essential part of the gauge, and is connected to the hollow casting **C** which is coupled by means of a copper pipe to the boiler, and is thus subject to the pressure inside the boiler. The other end of the tube is closed by a plug **A**. The pressure acting on the tube tends to make its section more nearly circular, and this in turn causes the tube as a whole to straighten out. By connecting the plugged end **A** of the tube by means of a link to a toothed quadrant **D** which gears with a small pinion **E**, it is possible to make a pointer **P** rotate over a scale marked off in pounds per square inch. The authorized working pressure must be marked on the scale with a red line. In order to prevent the hot steam from damaging the spring tube, it is usual to give the copper pipe connecting it to the boiler one or more complete turns, so that the steam may condense and the spring tube may fill with water. A small cock is provided where the copper pipe to the pressure gauge is connected to the boiler, in order that the gauge may be changed without blowing all the steam out of the boiler, and it is essential that this cock remain fully open when the engine is working, as otherwise a false indication may be shown on the gauge.

7

All boilers must be fitted with one or more blowdown cocks, connected to the lowest part of the boiler, for the purpose of blowing out any deposits of mud and scale which may collect. Intelligent use of the blowdown cock can greatly reduce the tendency towards foaming caused by high concentrations of salts dissolved in the boiler water, and also protects the plates and tubes from over-heating through deposits of mud. Some of the older boilers have only one blowdown cock, attached to the outer throat plate between the frames, but the more modern boilers have two blowdown cocks, one on each side of the firebox near the front corners of the foundation ring.

Several different designs of blowdown cock are used on the S.A.R., most of them arranged so that they can be worked from the cab. The types most commonly used are the 'Everlasting' and 'Hopkinson', which are shown in **Fig 41** and **Fig 41A** respectively.

The cock consists essentially of a chamber connected directly to the water space of the boiler, and closed by a cover to which the blowdown pipe is attached. Inside the chamber is a lever, mounted on a spindle extending through the cover, so that the operating handle may be attached. On the lever

is fitted a brass valve disc which slides across a face formed in the cover at the outlet opening. When the valve is closed the boiler pressure holds the valve tight against the face, and the lever closes the opening to the boiler, but not tightly. The lever thus prevents mud and scale from filling up the chamber of the cock, but allows the boiler pressure to hold the valve tight. When the valve is opened the spindle moves the lever carrying the valve disc, and slides this disc across the face. A spring is provided between the lever and the disc to hold it against the cover when in the open position, and so prevent grit from getting between it and the face over which it slides.

The pipe leading from the blowdown cock is usually fitted at the end with a baffle drum to break up the stream of water and steam, to prevent blowing away the ballast and to reduce noise. The baffle drum must be firmly secured, otherwise the stream will not be properly directed.

8

A boiler test plate must be fitted to all boilers, to indicate the authorized working pressure, the boiler number, and when the boiler was first put to work. On the S.A.R. the test plate is made of brass, and is fastened to the left hand side of the smokebox. In addition to the information mentioned above, the dates of examination and the dates and pressures of the various hydraulic and steam tests are stamped on the test plate.

Apart from the various compulsory boiler mounts mentioned, there are several other mounts fitted to S.A.R. boilers, as indicated on **Page 22**.

9

All locomotives are fitted with a regulator to control the flow of steam from the boiler to the cylinders. Two types are in general use on the S.A.R., the double beat regulator and the multiple valve regulator.

The double beat regulator is always placed in the dome on the top of the boiler barrel. The dome is made as high as the loading gauge will permit so that the steam may be taken from a point as high as possible above the water surface of the boiler, thus preventing as far as practicable the carrying over of small drops of water with the steam.

The drawing, **Fig 42**, shows the normal design of double beat regulator. It will be seen that the valve has two seats, and when open admits steam to the swan neck from above and below. When closed the steam pressure on the top of the upper part and below the lower part of the valve causes it to be nearly balanced, and therefore easy to work. The lower part of the valve is made slightly smaller in diameter than the upper part so that it will pass inside the seat of the upper valve, and also so that once closed there will be a slightly

greater force on the upper part than on the lower part thus tending to keep the valve closed.

The regulator rod runs from the socket shown in the regulator elbow over the firebox inner crown sheet, and passes through a gland in the outer back plate. The regulator handle is secured to the regulator rod, and moving the handle rotates the rod and operates the valve by means of the small crank formed near the end of the regulator rod and the link connecting the crank to the eyebolt through the valve.

All the more modern locomotives are fitted with the multiple valve regulator, which serves to control the flow of superheated steam to the cylinders, and **Fig 43** shows the construction of this regulator, which is incorporated in the superheater header. It consists essentially of three chambers, one above the other. The top chamber is connected directly to the internal dry steam pipe in the barrel, and is always full of saturated steam at boiler pressure. The centre chamber forms the main saturated steam compartment of the superheater header, to which the branch passages feeding the elements are connected. The bottom chamber is a balancing chamber which houses the balancing pistons of the main valves and the camshaft which operates the valves.

The valves consist of a small pilot valve and three, four or five main valves, according to the size of the regulator. Each of the main valves consists of a spindle with a mushroom valve near the top, a balance piston near the bottom, and below that two collars between which fits the operating cam on the camshaft. The action of the regulator is as follows:

The camshaft is rotated by means of a system of rods and levers connected to the regulator handle in the cab, and the first motion of the camshaft lifts the pilot valve. This allows steam to flow from the top chamber to the bottom chamber, until the pressure in both is equal. The main valves are now very nearly balanced, and little effort is necessary to lift them. The normal arrangement is for one valve to open at a time, the odd numbers before the even numbers, such as 1, 3, 2 or 1, 3, 2, 4 or 1, 3, 5, 2, 4, and the last one to open is the first one to close.

As each main valve opens the balancing piston rises in its guide, until four small holes are uncovered. These holes allow steam to pass into the balancing chamber from the centre chamber, and thus maintain the balance of the valves.

The smokebox is made with a large slot immediately above the regulator, and this slot is closed by a cover which is easily removed, thus allowing for repairs being effected to the regulator without having to dismantle the spark arrestor

and other parts in the smokebox. The regulator rods run along the outside of the boiler barrel, on either the right or left-hand side.

10

All the more modern boilers are fitted with a steam turret, placed on the outside firebox wrapper plate immediately in front of the cab. The largest boilers have two turrets, placed one on each side of the centre line, so that they will clear the loading gauge, and so that the valve operating hand wheels may be readily accessible inside the cab.

The turret is supplied with dry steam through a single internal pipe from the dome, or from the collector pipe where no dome is used, and is fitted with a main stop valve to isolate the turret for repairs. This avoids the necessity for blowing all the steam out of the boiler before repairs can be started.

The turret consists of a hollow casting provided with a number of pipe connections, each controlled by a valve, and all the steam required for the various auxiliaries is taken from these connections, thus avoiding the necessity of having a considerable number of internal dry steam pipes in the boiler, and greatly facilitating repairs. The auxiliaries mentioned normally comprise the following: injectors, ejectors, lubricator, blower, drifting valve, steam heating, headlight turbine, reversing engine, grate shaker donkey, mechanical stoker, whistle and any other fittings requiring steam. The valves are operated from inside the cab by means of rods fitted with handwheels.

11

The blower has already been dealt with on **Page 20**.

12

A scum cock is fitted to the outer back plate of many boilers, and is provided for removing froth and scum from the surface of the water in the boiler. It is quite effective in reducing the tendency towards priming when the boiler water is dirty. An internal pipe is usually fitted, extending upwards to about halfway between the inner and outer firebox crowns, so that the water level cannot be dangerously lowered. This protection cannot be entirely relied upon, as the internal pipe sometimes corrodes through or breaks off.

13

All locomotives are provided with a whistle, and on modern boilers this is usually attached direct to the turret.

In addition to the boiler mounts proper, there are a few other fittings which may be conveniently considered at this stage.

Washout plugs are provided on all boilers for cleaning and inspection of the water spaces. A number are arranged in suitable positions round the firebox, and some are fitted on the barrel and in the smokebox tube plate. They are tapered brass plugs, screwed into holes tapped in the outer plates of the boiler. They should never be interfered with while the boiler is in steam.

All the larger boilers are provided with small steam cylinders or 'donkeys' for rocking the grate. These cylinders are mounted under the footplate and are fitted with pistons and piston rods, which project through glands in the front cylinder covers and are coupled by means of links to levers on the grate operating shaft.

Two pipes are connected to each cylinder, one near each end, and these lead to a four-way operating cock mounted in a convenient position in the cab. Steam is supplied to the cock through a stop valve on the steam turret, and an exhaust pipe runs from the cock under the footplate.

By moving the handle of the operating cock to one side, steam is admitted to the cylinder through one of the pipes leading to it, while the other is connected to exhaust. Moving the handle to the opposite side reverses these connections, so that the piston is made to move backwards and forwards in the cylinder.

A small oil cup with a plug cock below it is coupled to the steam pipe between the turret and the operating cock, so that oil may be fed through the operating cock to the cylinder. This is the only means of lubricating the cylinder, and it is most important that oil be allowed to run through before the steam valve on the turret is opened.

Fig 44 shows a grate shaker steam cylinder and four-way operating cock.

Most locomotives are fitted with connections for supplying steam to passenger coaches for heating purposes. The steam pipe runs from a valve on the turret to a reducing valve, so arranged that the pressure on the discharge side of this valve cannot exceed 75 lb per square inch, which is the maximum pressure permitted in the steam heating system. From the reducing valve the pipe passes underneath the footplate, and is connected to the steam heating pipe on the tender by means of rubber hoses with special couplings. A pressure gauge is connected to the steam pipe on the discharge side of the reducing valve.

Nearly all the locomotives on the S.A.R. are equipped with electric lighting for the headlamp and the cab, and often at the rear end of the tender as well. Electricity is supplied from a small generator driven by a steam turbine, and mounted on the boiler or on the running board. Steam is supplied from a valve on the turret.

The generator produces alternating current at 32 volts and the latest model, known as type L.B.B., runs at 4,200 revolutions per minute provided the steam pressure is not less than 100 lbs per square inch. The turbine, which is directly coupled to the generator is of the impulse type, the steam being passed through a series of nozzles arranged round the edge of a wheel carrying one row of blades. A governor is provided to ensure that the turbine will run at an approximately constant speed with varying steam pressure.

When starting up the turbine, it should be given only a little steam for the first few minutes to allow it to warm up, and it should then be run up to full speed before switching on the lights. Leakage of steam past the valve on the turret when the turbine is not in use must not be allowed, as this causes wear on the governor parts, which is one of the main causes of over-speeding of the turbine and generator, and consequent burning out of lamps. Enginemen should watch the turbine exhaust pipe, and if steam is seen to be blowing through when the stop valve is shut, the valve should be booked for attention.

Many of the largest modern locomotives are equipped with mechanical stokers. Four types are now in use, but one of these is fitted to eight engines only, and while it is different in many respects from the other types, the principles are the same. Two are the Standard Stoker Company design and differ only in size, i.e. the coal handling capacity. They are known as the H.T.1 and H.T. stokers, the latter being the larger. The fourth type, the Berkeley stoker, is similar to the Standard Stoker design and equivalent to their H.T stoker. These two latter types have been fitted to the most recent locomotives placed in service.

The type H.T. stoker will be dealt with here. **Fig 45** and **Fig 45A** show the arrangement.

The stoker consists of:

(1) a conveyor and crusher unit in the tender, below the coal bunker;
(2) a telescopic intermediate conveyor unit between the tender and the locomotive;
(3) an elevator unit fastened to the firebox back plate;
(4) a distributing unit fastened to the elevator, consisting of steam jets, a distributing table and an air sealing apron;
(5) a steam engine mounted on the tender to drive the conveyors and the elevator.

The tender unit (1) consists of a conveyor screw working in a trough, a gear box at the rear end, and a crusher at the front end, the whole being rigidly secured to the tender frame. The supply of coal to the conveyor is controlled by means of sliding plates. The tender, intermediate and elevator conveyor screws are connected by universal joints, and are all driven from the gear box on the tender.

The intermediate unit (2) is made up of two tubes, one fitting inside the end of the other, and connected by means of ball and socket joints to the tender trough and to the elevator tube. Inside these tubes is the conveyor screw, which is flexibly connected to the tender screw and the elevator screw. This allows for all the required movement between the engine and the tender, while keeping the stoker working.

The elevator tube and conveyor screw (3) are connected to the intermediate unit, as described above, just below the cab floor, and extend through the floor to the firehole in the firebox back plate.

The coal distributor jets (4) are arranged on one box, each group of jets being fed with steam through a separate pipe controlled by a valve. The distributing table is hooked on to the distributor jet casting, and is held in position by two pins. The deflecting vanes on the top surface of the distributing table, together with variation in the steam supply to the jets, and the adjustable vanes in the upper portion of the elevator tube, provide for sufficient flexibility to distribute coal to any part of the firebox. To avoid overheating of the distributing table, cooling air is deflected against its underside by means of the air sealing apron.

The engine for driving the conveyors (5) is a two cylinder double acting reversible horizontal steam engine, mounted in either the left or right hand front corners of the tender. The lubrication of the cylinders and steam chests is provided either from an extra feed on the locomotive hydrostatic lubricator or by means of a mechanical lubricator driven off the stoker engine crankshaft. The crossheads, connecting rods, crankshaft, eccentrics, etc. are enclosed in an oil tight housing and are lubricated by splash. See **Section 6**, **Pages 58-60** for oil allowance and setting of hydrostatic lubricator.

On Garratt type engines the arrangement of the stoker gear is practically identical, the hind unit taking the place of the tender.

The engine is fitted with two piston valves, each having a single eccentric to drive it. It is reversed by a hand operated valve connected to the supply and exhaust piping, and movement of this valve interchanges the functions of the steam and exhaust ports of the engine. In other words the piston valves work with inside admission and outside exhaust when the engine is running

forward, and with outside admission and inside exhaust when running backward. The sketch, **Fig 46**, shows the arrangement of the reversing valve. When the valve is placed in the central or neutral position, steam is cut off completely.

The Berkley Stoker differs from the H.T. stoker mainly in the manner the coal is distributed by the distributing unit. In this case the coal is brought up the elevator tube and deposited on a flat surface or table which has no guiding ridges and which is a continuation of the jet box casting. There are no adjustable deflecting vanes near the top of this table. To ensure that the coal is deposited evenly on this surface there is a small portion of screw on the top of the elevator screw which is right handed whilst the screw is left handed. This prevents the coal being delivered all on one side of the table.

The distributing table portion of the jet box casting is protected from the fire by a large iron casting which fits on to the front of it. The sides of this casting form a continuation of the table for supplying coal to the back corners of the firebox.

On this stoker, there are four jet groups for distributing the coal, being named left and right front and back corners, in the same way as on the H.T. stoker. There is however no jet group to correspond with the 'Fine Coal' as used on the latter.

The Berkley stoker engine is reversed in the same way as the Standard Stoker engine but in this case the reversing valve is embodied in the stoker engine itself, the necessary steam and exhaust passages being cast in the engine block. This reduces the amount of piping in the stoker compartment considerably.

There are other minor differences in the design of couplings and control valve, etc., but these have no bearing on the principle of operation.

Fig 45B shows the arrangement of this stoker.

WATER SEPARATORS

One of the major troubles experienced with stoker engines has been water getting in from the steam end into the crankcase and emulsifying with the oil. This has been largely overcome by putting a water separator into the steam pipe before it reaches the engine. The new engines have this fitting and all other stoker fired engines will be fitted likewise as they pass through workshops.

SECTION 5

CYLINDERS: VALVES: RODS & MOTION

Cylinders. Pistons. Piston valves (inside admission). Expansive working. Lap & lead. Valve events. Indicator diagrams. Exhaust clearance. Piston valves with outside admission. Slide valves. Advantages of piston valves. Advantages of inside admission. Lagging. Glands & packing. Cylinder drain cocks. Exhaust drains. Inspection holes & caps. Snifting valves. Drifting valve. Bye-pass valves. Clearance. Lubrication of valves & pistons. Crossheads & slide bars. Connecting rods. Relative position of cranks. Names of various crank positions. Adhesion. Axle loads. Coupling of wheels. Names of wheels. Rods. Crankpins. Bushes. Balance weights. Sanding gear. Purpose & basic requirements of valve gear. Walschaerts gear - names of parts, modifications of normal arrangement, outside admission, coupling of parts, reversing arrangements (hand & steam operated). Stephenson link motion - position of eccentrics for direct & indirect motion, action of the motion, reversing arrangements. R.C. valve gear - alteration of cut-off, driving arrangements, lubrication, wire drawing of steam. Short & long valve travels. Regulator opening. Port openings. Direction of forces on slide bars. Indications of outside & inside admission valves.

In order to convert the pressure and heat energy in the steam into useful work, an 'engine' is required, which may consist of a turbine or of one or more cylinders each fitted with a piston and piston rod. Turbines are not normally used on steam locomotives, and as the backward and forward or reciprocating motion of the piston and piston rod must be converted to a rotary motion in order to turn the wheels, a crosshead, connecting rod and crank are required for each cylinder. All the normal non-articulated locomotives on the S.A. Railways are fitted with two cylinders, secured outside the frame.

The cylinder is a circular iron casting made with an additional chamber known as the steam chest. This is almost always above the cylinder, but occasionally at one side. Inside the cylinder is the piston, and as steam acts first on one side and then on the other, the piston is forced backwards and forwards. To make a steam tight joint between the piston and the cylinder, two or more grooves are machined in the edge of the piston, into which cast iron rings are fitted. These rings press against the cylinder wall, and prevent the steam from blowing past the piston. A tapered hole is machined in the centre of the piston, and the tapered end of the piston rod fits tightly into this hole, the rod being secured by a large nut. To prevent the nut from slackening off, a split cotter is used, or the end of the piston rod is lightly riveted over.

The cylinder has a cover at each end, secured by studs and nuts. The back cover has a hole in the centre through which the piston rod passes, and to

prevent steam from blowing past the rod, metallic packing is used, which will be described more fully later. The back cover has one or two heavy lugs cast on it, to which are secured the slide bars of which there are usually two, but sometimes one only. The cylinder is fitted with a cast iron liner inside to avoid wear on the cylinder casting itself. This liner is slightly tapered at each end, so that the piston will not wear a ridge at each end of its stroke, and also to enable the piston with the rings in position to be pushed into the cylinder easily when assembling. **Fig 47** shows the normal arrangement of a cylinder and steam chest.

Two types of piston (or piston head as it is sometimes called) are in use on the S.A. Railways, one being a single iron casting, hollowed out. inside for lightness, and the other consisting of two parts, a steel centre and a cast iron bull ring which is riveted to the centre. Grooves are machined in the bull ring to take the piston rings. The piston shown in **Fig 47** is of the bull ring type.

In order to distribute the steam first to one side of the piston and then to the other, and to allow the exhaust steam to escape after it has done its work, valves are provided for all cylinders. These are fitted inside the steam chest, and the most common type on the S.A. Railways is the piston valve. **Fig 47** shows a piston valve in position in the steam chest. Two other types of valve which are also used will be dealt with later.

The piston valve consists of two heads mounted on a common spindle. Each head has four narrow grooves machined in it for the reception of four valve rings, which are similar to piston rings, and which are provided to make a steam-tight joint between the valve head and the liner inside which the head works. Two liners are fitted to each steam chest, one at each end, and each liner is provided with a series of holes accurately machined in a row round the circumference, to allow the steam to pass into and out of the cylinder through a space between the liner and the steam chest wall. A passage called the port connects this space to the end of the cylinder. **Fig 48** shows the arrangement.

The valve heads may be solid iron castings, but more usually are built up of two steel discs and a cast iron ring carrier or bull ring, the heads being secured against shoulders machined on the spindle by means of nuts and split cotters. The drawing, **Fig 49**, shows the bull ring type of valve head.

The steam chest is provided with a cover at each end. The back cover has a gland in it through which the valve spindle passes, while the front cover usually also has a gland, as most valve spindles extend through this cover also. The valve spindle crosshead guide is either made in one piece with the back steam chest cover, or is attached to it.

As previously mentioned, the valve must be capable of controlling the admission of steam to each end of the cylinder in turn, while at the same time allowing the exhaust steam to escape after it has done its work. These first essentials can be obtained with a simple valve, as indicated in the drawing, **Fig 50**.

The piston is about to commence its forward stroke, as shown by the arrow next to the piston rod. The valve heads just cover the two ports, but as the valve is moving backwards in the direction of the arrow next to the valve spindle, the back port is on the point of opening to steam, while the front port is about to open to exhaust. As the ports open, steam will flow through the back port into the cylinder, and force the piston forward, while the steam in the cylinder in front of the advancing piston will flow out to exhaust through the front port. When the piston reaches the middle of its stroke, the valve has uncovered the ports completely, and its direction of travel is now reversed so that it starts closing both ports. This goes on until the piston reaches the end of the forward stroke, at which point the valve has again just covered both ports, and is about to open the front port to steam and the back port to exhaust, thus allowing the steam to force the piston back again.

An engine arranged in this manner would work, but it would be seriously wasteful of steam, as in effect only the pressure energy and not the heat energy of the steam is being used. It will be seen that steam is admitted for the full length of the piston stroke, and it has been found that this is not necessary in any type of steam engine. It can be proved conclusively that it is much more economical to cut off the supply of steam to the cylinder before the piston reaches the end of its stroke, and to allow the steam to expand considerably before the valve releases it to exhaust, thus using some of the heat energy of the steam as well as its pressure energy. Without going deeply into the thermodynamics of the subject, the diagrams, **Fig 51** and **Fig 52**, indicate the position.

In **Fig 51** the steam is admitted for the full length of the piston stroke, and if the pressure at any point in the stroke be plotted against the position of the piston, the heavy lines inside the cylinder will result. The average pressure acting on the piston throughout its stroke is clearly 200 lb per square inch. The diagram shows the action of the steam on one side of the piston only, but the effect on the other side will be exactly the same. When the piston is on its return stroke, with the valve open to exhaust, there will be no pressure acting against it in an ideal engine, giving the lower line on the diagram.

Fig 52 shows the effect of cutting off the steam at one quarter of the piston stroke. The pressure acting on the piston at any point in the stroke can be seen, and it will be found that the *average* pressure during the whole of the stroke is approximately 116 lb per square inch. As the steam is cut off at one

quarter or 25 per cent of the stroke, only one quarter of the quantity of steam is admitted to the cylinder during any one stroke compared with the arrangement shown in **Fig 51**, and yet the average pressure on the piston is rather more than half what it was when steam was admitted for the full stroke. This means that the steam is being used rather more than twice as efficiently. The more efficiently the steam can be used, the less coal and water are required.

In order to allow for early cut off, it is necessary to modify the valve by adding the 'steam lap' **L** to each head, shown in black in **Fig 52**. The valve must then start its movement in each direction rather earlier than in the simple arrangement shown in **Fig 50**, so as to open each port to steam in turn when the piston reaches each end of its stroke. In addition it has been found desirable to admit steam just before the end of the stroke, so as to allow the pressure to build up fully by the time the piston starts to move in the opposite direction, and to provide a cushion when the movement of the piston, piston rod, crosshead and connecting rod is reversed. Further, it is standard practice to open the port to exhaust before the end of the stroke, so that the steam still in the cylinder may be able to escape freely, and to close off the exhaust before the end of the return stroke so as to build up pressure by the time the port opens to steam. This involves advancing the travel of the valve still further.

The early opening of the valve to steam is known as 'lead', which may be defined as the amount that the port is open to steam when the piston reaches the end of its stroke. This is usually about 3/16 of an inch. The steam lap is the amount by which the valve head overlaps the port when the valve is in the central position and is usually about 1 inch to 1½ inches.

The type of piston valve so far described is known as the 'inside admission' type, as the steam from the boiler is admitted between the two valve heads, and the exhaust passages are arranged outside the heads. There are two exhaust passages, one from each end of the steam chest, and these are joined into one inside the smokebox saddle, through which the exhaust steam is led to the blast pipe in the smokebox, where it creates the draught, as described in **Section 4**. The inside admission piston valve is by far the most commonly used type of valve on the S.A. Railways, and indeed on most other railways. It is possible to arrange a piston valve to work with 'outside admission' and, as there are some locomotives so designed, this will be dealt with later. On the inside admission valve the steam lap is always constructed on the inner side of each valve head, as shown in **Fig 52**.

Referring again to the diagram drawn inside the cylinders in **Fig 52**, the point marked **1** is known as the point of admission, when the valve begins to open the front port to steam. The pressure rises almost immediately to the point **2**, after which it remains constant until the point of cut-off **3** is reached.

In this particular case this occurs at ¼ or 25 per cent of the stroke. After this the pressure falls steadily as far as point **4**, known as the point of release, when the valve begins to open the front port to exhaust. The pressure then falls rapidly until the piston reaches the end of its stroke at **5**, after which the pressure remains practically constant until the valve closes the exhaust at point **6**, known as the point of closure. From **6** to **1** compression occurs.

Going round the diagram again, the period between **1** and **3** is the admission period, during which the front port is open to steam; **3** to **4** is the period of expansion, when the front port is closed; **4** to **6** is the period of exhaust, during which the front port is open to exhaust, and **6** to **1** is the period of compression, when the front port is again closed. From **5** to **1** the small pressure acting against the piston is known as 'back pressure'. While this should be as low as possible, there must be a back pressure slightly higher than the pressure of the atmosphere, otherwise the steam would not flow out of the blast pipe, and the necessary draught could not be created as explained in **Section 4**.

The diagram shown inside the cylinder in **Fig 52** applies to the front port and the front of the piston only. A similar diagram can be drawn for the back port and the back of the piston, as conditions there are the same as in the front. The diagram is known as an 'indicator diagram', as in practice it is drawn when required by means of an instrument called an indicator, attached to the cylinder for this special purpose.

The lap and the lead given to the valve vary somewhat in different classes of locomotive, depending upon the detailed design of the valve and of its driving gear, but the principles remain exactly the same in all cases.

Some locomotives on the S.A. Railways are given a small clearance of about 1/16 inch on the exhaust edges of the valves. This is measured by the amount the ports are open to exhaust when the valve is in the central position over the ports. In the majority of locomotives, however, the exhaust edges of the valve are exactly in line with the outer edges of the ports when the valve is central. **Fig 53** shows a valve with exhaust clearance, and one without.

As previously mentioned, it is possible to have piston valves with outside admission, and these are in fact fitted to a number of locomotives of different classes on the S.A. Railways. With this arrangement, steam is supplied to the outsides of the valve heads, through two passages in the steam chest casting, and a single exhaust passage is provided between the heads. **Fig 54** shows an outside admission piston valve, and it will be noticed that the steam lap in this type of valve is constructed on the outer side of each valve head. Otherwise, the heads and their attachment to the spindle are the same as on the inside admission type.

In order to admit and exhaust the steam to and from each end of the cylinder, the outside admission piston valve must move in the opposite direction from the inside admission valve shown in **Fig 50**.

Another type of valve still used on several of the older classes of locomotives on the S.A. Railways is the slide valve. This valve is the same in principle as the outside admission piston valve, the only real difference being that it works on a flat seat instead of inside a cylindrical liner. The slide valve was one of the earliest types of valve to be used on locomotives, and the piston valve was developed from it. Slide valves are always arranged with outside admission.

The slide valve is a hollow box made of cast iron or bronze, the lower surfaces of which are machined flat, and slide over a seat attached to the cylinder. Slots are machined in the seat in line with the ports leading to each end of the cylinder, and to the exhaust passage. When the regulator is open the steam chest is in direct communication with the boiler, and the steam pressure on the back of the valve keeps it tight on its face. This causes considerable friction and a heavy load on the gear driving the valve, as well as making lubrication of the sliding surfaces difficult. The method used on the S.A. Railways to overcome these difficulties is to isolate about 65 per cent of the back of the valve from the pressure of the steam in the steam chest. This is done by fitting four strips into slots machined in the back of the valve, and pressing these strips outwards by small springs against a flat compression plate attached to the steam chest cover. If the valve strips are properly fitted, steam is excluded from the area inside the four strips, and a considerable load is removed from the valve. A small hole is drilled through the valve inside the area enclosed by the strips, so that any steam blowing past them will escape direct to exhaust rather than build up unwanted pressure on the back of the valve. This hole is usually known as the release port. **Fig 55** shows details of the construction of a slide valve.

The valve spindle is made with a frame or buckle which is an easy fit round the back of the valve, so as to allow the valve to lie close against its seat even when the seat and the valve face are worn down. If the buckle were a tight fit round the valve, the latter could easily be held clear off its seat, and would not function properly.

The advantages of a piston valve, either inside or outside admission, over a slide valve are that only about one-sixth of the force necessary to move a slide valve while the regulator is open is required for a piston valve, as the steam pressure acts endways on the valve heads instead of forcing the valve on to its seat. The piston valve is thus practically balanced. Further, a considerably greater length of port is available round a piston valve liner than is possible underneath a slide valve, thus giving a freer inlet and outlet for the steam. In

addition, a piston valve is much easier to lubricate effectively than a slide valve, particularly when the steam is superheated and is at a high pressure.

The advantages of inside admission over outside admission piston valves are that, in the former case, the valve spindle glands have to contend only with the low pressure exhaust steam instead of live steam at boiler pressure, as is necessary with an outside admission valve, and also that if the live steam can be kept away from long passages through the steam chest casting and from the steam chest covers, considerable loss of heat is avoided.

To prevent serious loss of heat from the outside of the cylinder and the steam chest, these are lagged with asbestos blankets, which in turn are covered with thin steel lagging plates. It is most important that the front cylinder cover be lagged, as when the locomotive is travelling forward, particularly in cold weather, a great deal of, heat can be lost through this cover. The back cover should also be lagged, but this can never be so effective since the piston rod gland. and the slide bar brackets take up a considerable part of the area of the cover. The cooling effect of the air is also not so serious on the back cover. The steam chest covers of locomotives with inside admission piston valves are not normally lagged, as some loss of heat from the exhaust steam is not important. With outside admission piston valves, however, the steam chest covers must be lagged, and similarly with slide valves the whole steam chest, which is usually in the form of a rectangular box, is lagged.

Enginemen should not fail to book defective or missing lagging for attention, as the heat lost through unlagged surfaces can only be supplied by burning more coal than is otherwise necessary. In extreme cases, condensation of the steam in an unlagged cylinder an produce sufficient water to knock out a cylinder cover or to cause other serious damage for which enginemen may be held responsible.

As previously mentioned, a steam-tight joint is made round the piston rod where it passes through the back cylinder cover by the use of metallic packing. One type of packing used on the S.A. Railways for superheated locomotives is shown in **Fig 56**.

The brass segment ring is made in three pieces, held together round the piston rod by three spring clips. The segment ring stops most of the steam from reaching the packing, although it is not a tight fit on the piston rod. The packing rings are made of a special type of copper and lead alloy and are fitted accurately to the rod in halves. The tapered shape of the rings causes the pressure of the spring to force them firmly against the piston rod, and to maintain a steam-tight joint. The whole of the packing arrangement is held in position in the stuffing box in the back cylinder cover by a cast iron gland secured to the cover by four studs. Pulling up this gland also compresses the

spring sufficiently to keep the packing rings tight against the rod. The packing used on saturated locomotives is generally similar to than shown in **Fig 56**.

If the piston rod packing blows on the road, there is little the driver can do to remedy the defect. On arrival at a depot he should book the packing to reset, or to renew if the blow is bad.

Valve spindles on locomotives with outside admission valves (piston or slide) are provided with metallic packing much the same as that used for piston rods, except that it, is smaller. On these engines the valve spindle does not usually project through the front steam chest cover, but often it is supported in a 'dummy gland' or socket with the outer end closed.

Locomotives with inside admission piston valves do not need metallic packing for the valve spindles, as only exhaust steam at a low pressure comes in contact with the glands. The regular practice is to pack the valve spindle glands with asbestos soaked in oil. On these locomotives it is usual to extend the valve spindle through the front steam chest cover.

All locomotives are fitted with a drain cock at each end of each cylinder at the bottom so that any water in the cylinders may be drained out. These cocks are useful when testing valves and pistons for defects. Drain cocks are operated by a rod underneath the cylinder, and must be opened if the locomotive stands for any length of time, as water is practically incompressible, and will cause serious damage if it is allowed to collect in the cylinders. Locomotives with inside admission valves usually have a third drain cock connected by a small pipe to the middle of the steam chest in order to drain out any water which may collect there. When a fourth drain cock is fitted, this is connected to the multiple valve regulator. It must be remembered that only the two outermost cocks are connected to the cylinder.

Some more modern locomotives having inside admission valves are provided with two open drain pipes connected to the exhaust passages at each end of each steam chest. Cocks are not fitted to these drains and thus, when the locomotive is working, a light puff of steam will be seen coming from the drain pipes at each exhaust beat.

Locomotives with piston valves have two inspection holes through the outside of each steam chest, arranged opposite the ports through each valve liner. These holes are closed by brass inspection caps.

Nearly all cylinders are fitted with an air valve or snifting valve, and on inside admission locomotives this is usually on the steam chest, between the valve heads. The purpose of these valves is to allow air to be drawn into the

cylinders to destroy the vacuum created by the moving pistons when the locomotive is drifting, and they help considerably in preventing gases from the smokebox from being drawn into the steam chests and cylinders and causing carbon deposits. Snifting valves also assist in allowing the locomotive to drift freely. There are several different designs of snifting valve in use, but they all work on the principle that they are held closed as long as the pressure inside the cylinder is higher than that of the atmosphere, but will open as soon as any vacuum is formed in the cylinder. **Fig 57** shows a common form of snifting valve.

A great many locomotives on the S.A. Railways are fitted with a drifting valve. The usual arrangement is to have a quick-acting valve supplied with steam from a stop valve on the turret. A pipe which branches into two near the front of the locomotive allows steam from the drifting valve to flow into both main steam pipes, and thence into the steam chests and cylinders. This small supply of steam to the front end while the locomotive is drifting with the regulator closed has three important advantages, which are (1) that the lubrication of the valves and pistons is greatly assisted, (2) that the cylinders and steam chests are kept hot, as comparatively little cold air has to be drawn through the snifting valves, and (3) that the tendency to create vacuum in the cylinders is reduced, thus largely preventing smokebox gases from being drawn into the steam chests and cylinders. At fairly high speeds the snifting valves alone cannot admit sufficient air to destroy the vacuum in the cylinders completely, and a locomotive will drift more freely with the drifting valve open than without. Decreasing the volume of air drawn into the hot steam chests and cylinders just after the regulator is closed has the further advantage of greatly reducing the tendency of the oil to burn and carbonize the ports, valve rings and piston rings.

Other devices frequently fitted to piston valve cylinders are bye-pass valves. A few locomotives are fitted with hand operated bye-pass valves, but usually they work automatically. The most common type is shown in **Fig 58**, and two of these are fitted to each steam chest.

These valves are provided to relieve the pressure built up in front of the advancing piston when the locomotive is drifting. One passage in each valve casing is connected direct to the steam chest, between the valve heads on an inside admission locomotive, and the other is connected to the space between the steam chest wall and the liner, and is thus permanently connected to the port to the cylinder. A feather port leads from the passage from the steam chest, and allows any pressure inside the steam chest to act on the larger face of the valve, thus keeping it on its seat. If for any reason the pressure in the cylinder exceeds the steam chest pressure sufficiently to overcome the difference in diameter of the two faces of the valve, the valve will be forced off

its seat, and the excess pressure in the cylinder will be relieved. This may happen when water is present in the cylinder, or when drifting.

When a locomotive is drifting, the valve gear should be placed in the position of maximum cut-off, which is usually about 75 per cent. The action of the bye-pass valve is then as follows:

Assume the cylinder to be full of air, and the piston to be just starting its forward stroke from the back cover. The valve will be clear of both ports, and the air inside the cylinder will be forced out of the front port into the exhaust passages, while air will be drawn through the snifter into the steam chest and down the back port behind the piston. The valve cuts off communication between the back port and the steam chest at 75 per cent of the piston stroke, and at about 90 per cent of the stroke the valve also closes the front port to exhaust. Pressure starts to build up in front of the piston, and this opens the front bye-pass valve, allowing the compressed air to flow into the steam chest. At the same time a partial vacuum is formed behind the advancing piston until the valve opens the back port to exhaust, when air from the exhaust passages destroys the vacuum.

Further movement of the piston forces more air through the front bye-pass valve until the front port opens to lead steam (point of admission) when the pressure in the cylinder and the steam chest will be equalized, and the front bye-pass valve will close. When the motion of the piston is reversed at the end of its stroke, the air still in the cylinder, the port and the steam chest (between the valve heads) is already compressed to some extent, and will expand to a pressure just below that of the atmosphere before the snifter opens. This reduces the amount of cold air drawn through the snifter. The use of the drifting valve reduces this still further, as mentioned previously.

When the piston moves away from the front cover, the same action will occur as described above, only with the back bye-pass valve. Bye-pass valves therefore relieve compression, but do not directly destroy vacuum in the cylinder. Indirectly they do help to reduce the vacuum formed at high drifting speeds, as less air has to be drawn through the snifter when bye-pass valves are fitted than without them.

It is not possible to allow the piston to travel right up to the front or the back cylinder cover as, if this were done, the slightest knock in the connecting rod bushes or in the driving axle-box would allow the piston to strike the cover, and there would be no provision for any expansion or contraction of the piston rod. Clearance is therefore allowed at both ends of the cylinder, which is usually from ⅜ to ½ inch. This is the distance between the piston and the cylinder cover when the piston is at the extreme end of its stroke.

Clearance volume is the volume left between the piston and the cylinder cover when the piston is at the extreme end of its stroke, together with the volume of the port from the cylinder up to the surface of the valve.

Lubrication of pistons and valves is essential if rapid wear is to be avoided, and this is provided for by feeding a small amount of oil from the hydrostatic lubricator in the cab into the main steam pipes close to the steam chests, so that the steam will distribute the oil to all the sliding surfaces. On most locomotives there are also feeds direct to the cylinders. The whole question of lubrication is dealt with more fully in **Section 6**, but it may be mentioned here that an additional supply of oil is fed to the piston rods and the valve spindles from auxiliary oil cups in order to lubricate the packing.

CROSSHEADS, CONNECTING & COUPLING RODS

In order to transmit the force exerted on the piston to the wheels, and to convert the reciprocating motion of the piston into a rotary motion, it is necessary to have a crosshead, a connecting rod and a crank for each cylinder.

The crosshead is usually a steel casting with a tapered socket at the front end into which the tapered end of the piston rod fits accurately. A slot is cut through the piston rod and both walls of the socket, and a large flat draw cotter is driven tightly through the socket and the rod, pulling the two firmly together. The cotter is prevented from working out by a split pin or other locking device. The crosshead is provided with two slippers, which are normally made of cast iron with pockets filled with white metal. These slippers slide on the slide bars, of which there are usually two but on certain classes of locomotives only one for each cylinder. The slide bars are secured in front to either one or two lugs cast on the back cylinder cover, while at the back they are fastened to a strong bracket attached to the locomotive frame. This bracket usually forms part of the 'motion plate' from which the valve motion is hung, but on older locomotives is often in the form of a 'spectacle plate' supporting the slide bars only. The slide bars are fastened to their supports by strong bolts or studs.

Slide bars and crosshead slippers are essential to guide the piston rod along the centre line of the cylinder, and to take the thrust developed when the piston rod and the connecting rod are not in line with each other.

Three different types of crosshead are in use on the S.A. Railways, and there are detailed differences in the design of each type when applied to different classes of locomotive. A representative example of each type of crosshead is shown in **Fig 59**.

The connecting rod is coupled to the crosshead by means of a pin passing through the two main walls of the crosshead and through the hole in the small end of the connecting rod. This pin is called the gudgeon pin, and is always locked in the crosshead, while the small end turns on it. The locking arrangement consists of tapering the gudgeon pin at each end and fitting these ends into tapered holes in the walls of the crosshead, together with a small key in the inner hole of the crosshead. A large nut is screwed on to the outer end of the gudgeon pin, and this nut is prevented from turning by a locking device, which usually consists of a small toothed plate fastened to the crosshead by set screws and engaging with corresponding teeth cut on the edge of the nut. The small end of the connecting rod is fitted with a bronze bush, which is almost always lubricated with grease.

The big end of the connecting rod also has a bush fitting over the driving crank pin, which is pressed firmly into a boss on the driving wheel. The distance from the centre of the crank pin to the centre of the axle is exactly half the length of the piston stroke. On all two cylinder locomotives the cranks on the two wheels fitted to any one axle are arranged so that one leads the other by one quarter of a turn, and on the S.A. Railways it is always the right hand crank which leads when the locomotive moves forward. **Fig 60** shows the arrangement.

The reason for this is to make it possible to start the locomotive from any position, even if one crank is in the dead centre position, because then the other crank is at its point of maximum turning effort. The diagram, **Fig 61**, shows the names used for the various positions of the crank round the wheel.

The following examples show the relative positions of the cranks on the two sides of the engine:

(1) Right hand crank on bottom quarter, left hand crank on front centre
(2) Right hand crank on back centre, left hand crank on bottom quarter
(3) Right hand crank on top front angle, left hand crank on top back angle
(4) Left hand crank on bottom front angle, right hand crank on bottom back angle

It will be seen that if the position of one crank is known, the position of the other crank can be found immediately if it is remembered that the right hand side leads the left hand side by 90° or a quarter of a turn when running forward. The right and left hand sides are always taken when looking from the cab towards the cylinders.

The force exerted on the pistons is transmitted to the driving wheels by means of the connecting rods, as mentioned earlier, but unless there is sufficient adhesion or frictional grip between the wheels and the rails, the

wheels will slip and the locomotive will not pull its load. Adhesion depends largely on the load on each pair of wheels, usually called the axle load, and as the track will not safely stand loads greater than a certain amount it is necessary to limit axle loads to this figure. This in turn limits the adhesion available on any one pair of wheels and if large loads have to be hauled it is therefore necessary to provide more than one pair of wheels turned by the pistons and connecting rods. The normal way of doing this is to couple several pairs of wheels of the same diameter together, while using only two cylinders and two connecting rods. The wheels are coupled by means of coupling rods on each side of the locomotive, and every wheel has a crank pin over which the rods fit. **Fig 62** shows the arrangement of the connecting and coupling rods on one side of an eight wheel coupled locomotive. The knuckle joints are necessary to allow the coupled wheels to move up and down over track irregularities.

All rods are provided with bushes where they fit over the crank pins, the usual arrangement being grease lubricated floating bushes made of a special type of brass. When oil is used as the lubricant, the bushes are fixed in the rods and are made of hard bronze with pockets filled with white metal. To prevent the rods from working off the crank pins, a collar is used, secured either by two nuts or by a bolt through a hole in the centre of the crank pin. The connecting rod big ends are fitted outside the coupling rods, and on most locomotives are prevented from working off by the eccentric crank which is secured to the crank pin. Where no eccentric crank is used, two nuts hold a collar against the big end.

Every coupled wheel is fitted with a balance weight to balance the weight of the crank and of the rod attached to the crank pin. The driving wheels have larger balance weights than the other coupled wheels, since as well as the coupling rods, the connecting rods require balancing to some extent.

While adhesion depends largely on the weight on the coupled wheels, the state of the rails and the wheel tyres also has some effect. If the rails are wet or slippery the coupled wheels will not grip satisfactorily, and locomotives are therefore fitted with sanding gear to increase the grip when necessary. A sand box is fitted to each side of the locomotive, usually just below the running board near the slide bars. At the bottom of each sand box a valve is fitted to control the flow of sand to the sand pipes which deliver it to the rails just ahead of one of the pairs of coupled wheels, normally the leading wheels. The sand valves are worked by a system of rods and levers coupled to a hand lever in the cab. The sand in the boxes must be thoroughly dry, or it will cake and block the sand pipes.

VALVE MOTION

The valves in the steam chests have to be moved backwards and forwards as described earlier in this Section, and to do this a valve gear or motion is provided for each of the two cylinders. The essential requirements of a valve gear are:

(1) to open and close the ports when required;
(2) to enable the cut-off to be varied to suit the work the locomotive is required to do;
(3) to cause the locomotive to run forwards or backwards as desired;
(4) to be of simple and reliable construction.

Two types of valve gear are used on the S.A. Railways for locomotives fitted with either piston or slide valves: the Walschaerts gear and the Stephenson link motion. The Walschaerts gear is the type used on the great majority of locomotives fitted with piston valves and on certain classes fitted with slide valves, and may be regarded as the normal standard at the present day. It was invented in 1844 by a Belgian engineer named Walschaerts and is now probably the most commonly used locomotive valve gear in the world. **Fig 63** shows the normal arrangement of the gear for valves with inside admission.

The gear consists essentially of two elements, the first being the motion derived from the crosshead by means of the union link and the combination lever. This lever is designed so that the movement of the crosshead from one end of the piston stroke to the other will move the valve spindle through a distance equal to twice the steam lap plus twice the lead, and this movement remains constant for all positions of cut-off, in both fore-gear and back-gear. On a modern locomotive with a steam lap of 1½ inches and a lead of 3/16 inch, the combination lever alone will move the valve through a total distance of 3⅜ inches during each stroke.

The second element gives a variable movement to the valve spindle so that cut-off can be set where desired, and so that the motion of the valve can be completely reversed, thus reversing the engine. This variable movement is added to that given by the combination lever, and is obtained from an eccentric crank mounted on the end of the driving crank pin, and so set that the pin of the eccentric crank revolves round the centre of the axle at a definite radius. The eccentric rod connects the pin of the eccentric crank to the bottom of the curved expansion link, which is carried at its centre on trunnions working in brackets attached to the motion plate on the engine frame. The movement of the eccentric crank thus causes the expansion link to rock backwards and forwards on its trunnions through a definite angle each way.

The radius rod joins the combination lever to a die block which can be made to move up or down in the expansion link by means of the lifting arm on the reversing shaft and a lifting link connecting this arm to the radius rod. It is obvious that when the die block is in the centre of the expansion link, directly in line with the trunnions, no movement of the expansion link will be transmitted to the radius rod. This is the 'mid-gear' position, and movement of the valve is derived from the combination lever alone. Similarly, the further the die block is from the central position, the greater will be the movement given to the radius rod and thus to the valve spindle, and this is the manner in which the cut-off is controlled.

In the usual design of a Walschaerts valve gear, as applied to the majority of locomotives, the die block is in the lower half of the expansion link when the engine is in fore-gear, and in the upper half when in back gear. The motion is thus 'direct' in fore-gear, that is, in the same direction as the movement of the eccentric rod, and 'indirect' in back-gear, or in the opposite direction to that of the eccentric rod. With this design of gear on a locomotive with inside admission piston valves, the eccentric crank is arranged so that its pin is approximately 90° or a quarter of a revolution behind the driving crank pin when the wheel is turning forwards. The gear shown in **Fig 63** is of this type.

Certain classes of articulated locomotives have a modified Walschaerts gear on either one or both of the units. This is arranged so that the die block is in the upper half of the expansion link when in fore-gear and in the lower half when in back-gear, and the eccentric crank is then arranged to lead the driving crank pin by approximately 90° instead of following it, providing inside admission valves are used.

For locomotives with outside admission valves, either piston or slide, the Walschaerts gear is coupled up slightly differently, in that the radius rod is connected to the combination lever *below* the valve spindle instead of above it. In addition, with the normal design having direct motion in fore-gear and indirect motion in back-gear, the eccentric crank leads the driving crank in by approximately 90° when the wheel is turning forwards.

The various rods are coupled together by means of steel pins each of which usually works in a bronze bush in one of the rods, while it is locked in the forked end of the other rod by two taper pins. On some locomotives certain of the joints are fitted with roller bearings instead of plain bushes. Lubrication of the joints is by means of oil or soft grease.

To keep the valve spindle moving truly along a straight line, some type of guide is required, and on most modern locomotives this takes the form of a small crosshead sliding over a single bar or between two or four guides, which are either fixed to the back steam chest cover, or are made in one piece with

it. The combination lever is coupled to the valve spindle crosshead and thus the front portion of the motion is supported.

For maximum cut-off, which is usually at 75 per cent of the piston stroke, the valve is given its maximum travel, so that the die block is then at the extreme end of the expansion link. As the cut-off is shortened the valve must travel through a shorter distance, and to do this the die block is moved nearer to the centre of the expansion link. Adjustment of the cut-off as well as reversing of the engine is done by the reversing gear. This consists of a shaft running across the engine frame, with a lifting arm at each end, to which the lifting link coupled to the radius rod is usually connected. On some locomotives the lifting link is dispensed with by arranging a small rectangular block on the end of each lifting arm, and extending the radius rod beyond the expansion link. The block fits into a slot in the extension of the radius rod.

On the right hand end of the reversing shaft, a third arm is attached approximately at right angles to the lifting arms, and pointing upwards. This arm is used to turn the reversing shaft, and thus lift or lower the radius rods and the die blocks. Some locomotives are fitted with a screw mounted on a strong frame in the cab. This screw works in a nut which engages the forked end of the reversing lever, which in turn is coupled to the vertical arm of the reversing shaft by means of the reversing rod. A pointer on the nut moves over a graduated scale to indicate to the driver whether the locomotive is in fore-gear, mid-gear or back-gear, and the cut-off at which the engine is working. **Fig 64** shows the arrangement of the screw reversing gear.

Most locomotives having Walschaerts gear are fitted with a steam reversing engine on the right hand side, which is coupled direct to the vertical arm of the reversing shaft. The reversing engine consists of a steam cylinder and an oil cataract cylinder in line with each other, and mounted on a strong frame bolted to the locomotive frame. The steam cylinder moves the valve gear while the oil cylinder holds it in the position required. **Fig 65** shows the arrangement of the steam reversing engine.

It will be seen from the drawing that the pistons in the two cylinders are joined together by a single piston rod, in the middle of which is a buckle. A sliding block connected to the top of the vertical arm fits inside the buckle, thus transmitting the motion of the piston rod to the reversing shaft. The steam cylinder has a small slide valve in a steam chest and is supplied with steam from a stop valve on the turret. The slide valve is moved by a rod connected to a hand lever in the cab, and thus the steam piston and the piston rod can be made to move in whichever direction is desired. A system of rods and levers connects the slide valve on the steam cylinder with the cataract valve on the oil cylinder in such a way that when steam is admitted to one side of the steam piston and the piston rod moves, the oil in the oil

cylinder is allowed to pass from one side of the oil piston to the other. When the valve gear has been moved as much as is desired, the hand lever in the cab is replaced in the central position, and both the steam and the cataract valves are closed. As the oil cylinder and its ports are completely filled with oil on both sides of the piston, and as oil is practically incompressible, it follows that once the cataract valve is closed the whole reversing engine and the reversing gear are locked.

A rod connected to the piston rod of the reversing engine runs back to the cab, where it moves a pointer over a graduated sector plate, thus indicating to the driver the exact position of the reversing gear.

The steam piston is fitted with the usual style of cast. iron piston rings, and the gland is packed with an asbestos packing. The oil piston is fitted with a leather bucket of cup shape on each side of it, which prevents the oil from working past the piston, and the piston rod glands are packed with an asbestos packing.

The other type of valve gear used on many of the older classes of engines on the S.A.R. is the Stephenson Link Motion. This motion is a development from the single eccentric used to move the valve of a stationary engine, which normally runs only one way. As stated earlier, a locomotive valve gear must be able to provide variable cut-off and also the engine must be reversible. The Stephenson motion is designed with two eccentrics, one for forward and one for backward running, and these are connected to a slotted link so that either the fore-gear eccentric or the back-gear eccentric or both can be made to move the valve.

The eccentrics, of which there are four, two to each valve, are secured to the driving axle between the frames. **Fig 66** shows the design of a complete eccentric.

As previously mentioned, in order to allow for the lap and the lead of the valve, the movement must be advanced to some extent. In the Stephenson motion, as on a stationary engine, this is obtained by moving the eccentrics round the axle through an angle of about 20°, known as the 'angle of advance'. When the valve is driven directly without using a rocking lever, the motion is said to be direct, and the eccentrics are arranged on the axle as shown in the diagram, **Fig 67**, which also shows the position of the eccentrics for indirect motion.

It must be understood that the position of the eccentrics shown in **Fig 67** are for valves with outside admission, whether slide valves or piston valves. On the S.A. Railways very few locomotives with inside admission piston valves

are fitted with Stephenson link motion, and as these are all on the scrapping list, the arrangement of the gear will not be discussed here.

Fig 68 shows the arrangement of a typical Stephenson link motion with indirect drive to the valve. The expansion link is moved up or down over the die block by means of the lifting links coupled to the lifting arm on the reversing shaft, so that when the expansion link is in its lowest position, the die block is at the top of the link, in line with the fore-gear eccentric rod. This is the position of maximum cut-off in fore-gear. Similarly when the expansion link is in its highest position, the locomotive will be working with maximum cut-off in back-gear, and when the link is in the middle position the die block will be in the centre of the link which is the mid-gear position. In order to shorten the cut-off or 'notch up', the link is moved so that the nearer the die block is to the centre of the link, the shorter is the cut-off obtained. In such a position, both eccentric rods help to control the movement of the valve.

One of the features of the Stephenson link motion is that the lead of the valve is not constant, as it is in the Walschaerts motion. The lead of the valve increases as the cut-off is shortened, and is at a maximum in the mid-gear position.

The various parts are coupled together by means of pins working in bronze bushes in a manner similar to that used on the Walschaerts gear. On the S.A. Railways oil is always used for lubricating the Stephenson motion, and roller bearings are not employed.

The valve spindle is not usually provided with a crosshead to guide it, but is normally extended backwards, where it works in a bracket attached to the locomotive frame.

The reversing shaft is turned by a hand operated screw gear in the cab, similar to that already described, and a steam reversing engine is not used. To help to balance the quite considerable weight of the expansion links, lifting links and lifting arms on the reversing shaft, it is usual to provide a spring connected at one end to a small lever on the reversing shaft, and at the other to the locomotive frame. Certain old locomotives have two heavy weights carried on arms on the reversing shaft opposite the lifting arms. These weights gave rise to the old name of 'weight bar shaft', which was later corrupted to 'weighbar shaft'. The standard name today however is 'reversing shaft', and this applies to both the Stephenson and the Walschaerts gears.

ROTARY CAM VALVE GEAR

Certain locomotives on the S.A.R. have been fitted with valves and valve gear entirely different in principle from those already described. The locomotives concerned are Classes 15E, 16E, 19C and 20, and the gear is the Rotary Cam or 'R.C' Poppet valve gear. The intention of this type of gear is to improve the steam distribution to the cylinders. A piston valve or a slide valve has to control eight separate events for each revolution of the wheels - admission, cut-off, release and compression at both ends of the cylinder - and alteration of the cut-off affects the other events as well, no matter how the valve is designed. Further, with fairly short cut-offs, a piston valve or a slide valve does not open the port fully, and in addition it moves comparatively slowly so that at one end of the cylinder or the other it is always restricting the port opening.

If the cylinder be provided with four valves, one for steam and one for exhaust at each end, it simplifies the distribution of steam considerably, and each valve is required to control only two events instead of eight. Each valve opens and closes only once for every revolution of the wheels, so that each steam valve controls only admission and cut-off at one end of the cylinder, and each exhaust valve only release and compression at one end of the cylinder. If the valves are operated in pairs by a cam for both steam valves and a separate cam for both exhaust valves, it is possible to make the admission and cut-off independent of the exhaust and compression, which cannot be done with a piston valve or a slide valve.

The R.C. valve gear makes use of this possibility by providing a series of steam and exhaust cams so designed that the valves are opened rapidly, held fully open for as long as is necessary, and then allowed to close rapidly under the action of springs. This prevents throttling or 'wire drawing' of the steam, even at short cut-offs.

The general principle is similar to the way the valves of a motor car engine are worked, but there are certain important differences. The first is that the valves are of the double beat type, somewhat similar to those used in double beat regulators. The second is that to provide for different cut-offs, it is necessary to have more than one cam to each pair of valves. In the latest design only four cut-offs are provided in fore-gear, and one in back-gear, being at 85 per cent, 65 per cent, 50 per cent and 35 per cent of the piston stroke in fore-gear, and at 85 per cent of the piston stroke in back-gear. No other cut-offs are available, as each steam cam gives one cut-off only. In mid-gear the exhaust valves remain closed and the steam valves remain fully open. This gives an excellent bye-pass arrangement while preventing smokebox gases from entering the cylinders. Locomotives with R.C. valve gear are always

placed in mid-gear when drifting. Shifting valves and bye-pass valves are not fitted, as they would serve no purpose.

The valves are housed in four horizontal chambers, two at each end of the cylinder, and so arranged that the steam and exhaust chambers at each end are both connected to the port to the cylinder. The steam and the exhaust pipes are connected to the respective chambers at each end. A space is left between the two pairs of chambers into which the cam box is fitted at right angles to the centre line of the cylinder. **Fig 64** shows a view of the top of the cylinder, with the four chambers.

Each valve has a long stem working in a horizontal guide, and the stem projects through a small gland up to the side of the cam box. Inside the cam box, opposite each valve stem, is a tappet which pushes the valve open, while a spring mounted at the outer end of the valve pushes the valve closed again. The tappet is moved by a lever pivoted at the bottom of the cambox, and carrying a roller which runs on the surface of the cam concerned. **Fig 70** shows the arrangement of one exhaust valve: the steam valves are similar.

It will be seen that the valve has two seats, and that it is hollow. When the valve is open, steam passes between it and the outer seat, and also through the hollow in the valve and past the lower seat.

The valve spindles, the tappets and the levers with the rollers, are of course, in fixed positions, so that in order to engage different cams for the various cut-offs and to reverse the engine the camshaft is made to slide inside the cam box. This is done by means of a system of shafts coupled together by gears, and controlled from a handwheel in the cab. Behind this handwheel is a circular disc with notches cut in, into which a small catch fits. It is most important that the catch should be dropped into the notch, as otherwise the cams concerned will not be properly in line with the rollers, and damage will result. When changing from one cut-off to another while the locomotive is running, the handwheel should be turned as quickly as possible.

Each camshaft is driven from a gear box mounted on a return crank on the end of the driving crank pin. The pin of this return crank is exactly in line with the centre of the driving axle. From this gear box, the drive is transmitted through a tubular shaft fitted with universal joints and a centre support bearing to another gear box mounted on the outer end of the cam box.

The cam boxes with their gears, the gear boxes on the return cranks, and those on the control gear must all be kept filled up to the proper level with the correct grade of oil. The universal joints and other moving parts are lubricated by soft grease. Lubrication of the pistons is provided by a feed from the hydrostatic lubricator in the cab to each cylinder, as for a piston valve

engine. Lubrication of the poppet valves themselves is unnecessary as these valves do not slide, but the valve stems need a small amount of lubrication. This is provided in exactly the same way as on a piston valve locomotive, i.e. by a feed to each steam pipe.

GENERAL CONSIDERATIONS

On locomotives fitted with piston valves or slide valves the ports can never be opened or closed very rapidly, and further at short cut-offs the ports are not fully opened. At low speeds this does not have any serious effect, but when speeds are high considerable power may be lost just because the steam is throttled or 'wire drawn' when entering the cylinder, and is choked back when exhausting. This trouble can be reduced by giving the valves a longer travel and by decreasing the lengths of the ports from the steam chests to the cylinders as well as by increasing their area. It has been found that locomotives with a long valve travel can be worked effectively at shorter cut-offs (and therefore more economically) than locomotives with a short valve travel. There are, however, practical limitations to the length of the valve travel and to the size of the ports.

An example of an indicator diagram taken at high speed is given in **Fig 71**, and if this is compared with the diagram shown in **Fig 52**, which is an ideal diagram, the difference will be obvious.

It is clear that the wider the regulator is open the more pressure is available in the steam chest, and therefore the more steam will enter the cylinder during the short time the port is open. This is particularly important at fairly high speeds, and the most economical way, to work is with the regulator as wide open as circumstances will allow, and with a cut-off as short as the locomotive will stand without choking the exhaust and causing severe back pressure and knocking of the connecting rods and driving axle-boxes. Most modern locomotives are fitted with a pressure gauge in the cab which indicates the pressure in the steam chests. This is a most useful fitting and gives the driver valuable information. The steam chest pressure should be kept as high as circumstances, such as load, gradient and permissible speed, will allow.

From the descriptions of the valves and valve gears already given, it is possible to work out which ports will be open to steam or to exhaust and which will be closed when one big end is at any given point round the wheel, and the valve motion is set at any particular cut-off. Three examples are given overleaf, as a guide:

(1) If the right hand big end is on the bottom quarter, the left hand big end will be on the front centre. This means that the right hand piston is approximately in the middle of its stroke from the front cover to the

back cover, assuming the locomotive to be moving forward, and that the left hand piston is at the extreme front end of its stroke. If the motion is set in full fore-gear, which gives cut-off at about 75 per cent of the piston stroke, it follows that on the right hand side the front port will be open to steam, and the back port will be open to exhaust. On the left hand side the front port will be open to steam, as the valve always has some lead. This is often described as the front port being open to 'lead steam'. The back port will be open to exhaust.

(2) Taking the big ends in the same positions as before, if the motion is in mid-gear, both ports on the right hand side will be closed, as the valve will be in its central position. On the left hand side the front port will be open to lead steam and the back port will be open to exhaust since the valves have lead in all positions of the motion. (The above does not apply to a locomotive with R.C. poppet valve gear.)

(3) If the motion is in full back-gear, and the big ends are in the same positions as before, the pistons will also be in the same positions, and the only difference will be that the right hand piston will now be on its forward instead of its backward stroke. The right hand front port will then be open to exhaust and the back port will be open to steam. There will be no difference on the left hand side, as whichever way the wheels are turning the piston must move away from the front cylinder cover.

The fundamental points to remember when working out port openings are:

(1) That the right hand crank and big end leads the left hand crank and big end by one quarter of a turn, when locomotive is running forwards.

(2) That the position of the big end indicates closely the position of the piston.

(3) That cut-off is indicated by the percentage of the stroke of the piston.

(4) That the direction in which the big ends on a driving wheel are turning indicates the direction in which the piston is moving.

(5) That all valves are given lead both in back-gear and in fore-gear, and that with Walschaerts or Stephenson motion the valves also have lead in mid-gear. It therefore follows that when the piston is at the end of its stroke, the port at that end will be open to lead steam in any position of the reversing gear.

(6) That valves open to exhaust (point of release) before the end of the piston stroke, and that they close the exhaust (point of closure) before the end of the return stroke of the piston, giving compression.

The question of port openings will be dealt with in more detail in **Section 10**. Apart from guiding the piston rod and the piston, the crosshead and the slide bars are essential to take the thrust of the connecting rod, as mentioned

earlier in this Section. The diagrams shown in **Fig 72** indicate which slide bar takes the thrust in various circumstances.

It will be seen that while steaming in fore-gear the top bar takes the thrust, and while steaming in back-gear the bottom bar takes the thrust. This is true for all positions of the big end except when it is on front or back dead centre, as then there is no thrust, and the crosshead must rest on the bottom bar under its own weight.

While drifting in fore-gear the bottom bar will take the thrust, and while drifting in back-gear the thrust will be upwards, but as the force required to move the piston is not very great the upward thrust may not be much more than the weight of the crosshead, and the portions of the piston rod and the connecting rod which it supports, so that the thrust on the top slide bar will probably be very small, and the crosshead will more or less float.

There are several indications as to whether a locomotive is fitted with valves having inside or outside admission.

1. Slide valves always work with outside admission.
2. With piston valves driven by means of Walschaerts gear, the radius rod is coupled to the combination lever below the valve spindle crosshead for outside admission, and above the valve spindle crosshead for inside admission.
3. With outside admission piston valves, the snifting valves are always at or very near the ends of the cylinder or of the steam chest, while with inside admission the snifting valve is in the centre.
4. When bye-pass valves are fitted, and they are arranged with their covers facing away from each other, this is an indication of onside admission, while if they face towards each other it is an indication of inside admission.

SECTION 6

LUBRICATION

Friction and its results. Sliding friction. Fluid friction. Substitution of fluid friction in lubricant for sliding friction. Other uses of lubricants. Lubricating films. Types of lubricant used. Where each main type is used. Hydrostatic lubricator. Mechanical lubricator. Filling & starting the lubricator. Rate of feed. Atomisers. Drifting valves. Choke valves. Shutting off the lubricator. Blowing out of lubricators. Important points to remember. Air lock in lubricator. Blocked choke valve. Worn choke valve. Throttling of feeds. Transfer filler. Mechanical lubrication. Worsted trimmings. Tail, horn, plug, eccentric strap & arch trimmings. Cane corks. Renewal of trimmings. Removal of tail trimmings while standing. Soft grease nipples & grease gun. Automatic grease lubricators. Hard grease nipples & grease gun. Grease pads & containers. Waste packing for axle-boxes. Lubrication of roller bearing axle-boxes. Waste of lubricants. Cleanliness. Minor lubrication. Parts which must not be neglected. Rail & flange lubricators.

The purpose of lubrication is to reduce the friction which always occurs when one object slides over another. No matter how smooth the surfaces in contact are made, there is always a certain amount of roughness and unevenness, and when one surface slides over the other, the roughnesses on the one interlock with those on the other, and force is necessary to start and keep up the movement. The result of this friction, which is usually known as sliding friction, is to cause considerable heat and wearing of the surfaces touching each other. Three fundamental facts about sliding friction should be remembered, viz:

(1) that friction increases with increased pressure per square inch between the surfaces;
(2) that friction varies with the condition of the surfaces and with the materials of which they, are made;
(3) that friction is much greater at the beginning of motion than after motion has actually started.

Apart from sliding friction, there is an entirely different type of friction, known as fluid friction, which occurs when the particles of a liquid or of a gas move in contact with one another or with solid surfaces. This is the friction set up in an oil or a grease when it acts as a lubricant between two solid surfaces, but as fluid friction is very small indeed compared with ordinary sliding friction, its results are not serious. Further, fluid friction, although causing some heat, does not cause wear.

In order to eliminate the sliding friction which would occur between a journal and a bearing (such as an axle-box, for example) it is necessary to ensure that

at all times there is a film of lubricant between the sliding surfaces, and further that this film is thick enough and strong enough to prevent actual contact between the surfaces. The fluid friction in the lubricant then takes the place of sliding friction, wear is prevented and the amount of heat produced is small.

Lubricants serve certain other purposes, the most important of which are:

(1) prevention of corrosion;
(2) washing away of particles of dirt or dust; and
(3) cooling of the bearing surfaces.

The first and second are of considerable importance, but the third does not usually apply to steam locomotives.

The film of lubricant between the moving solid surfaces may be extremely thin, but this does not matter at all as long as the film does not break down. Failure of the lubricating film will immediately allow sliding friction to occur between the solid surfaces, which will result in excessive heat and wear. In bad cases the parts may tend to weld together and 'seize'. When this happens severe damage is invariably done, and the parts concerned often have to be scrapped.

In order to maintain the lubricating film in all the circumstances likely to arise in service, different types of lubricant are needed for use on different parts of a locomotive. The four main classes of lubricant used are given below:

(1) Cylinder oil
(2) Engine oil
(3) Soft grease
(4) Hard grease or driving journal compound

Several other grades of oil and grease are used on locomotives for special purposes, but as these are not the direct concern of the driver,, they will not be dealt with here. Instructions issued by the Chief Mechanical Engineer give full details of the parts to be lubricated by the shed staff, and what types of oil or grease are to be used.

As far as enginemen are concerned, the following list of parts and the lubricant to be used covers all normal requirements. It should be noted, however, that on certain classes of locomotives, oil is used for lubricating many parts which on other classes are lubricated with either hard or soft grease.

Part	*Lubricant*
Valves & Pistons	Cylinder oil
Valve motion	Engine oil or soft grease
Slide bars	Engine oil
Small ends	Soft grease (usually)
Coupling rods & big ends	Hard grease or engine oil
Coupled wheel axle-boxes	Hard grease or engine oil
Bogie & bissel axle-boxes	Engine oil, except for roller bearing boxes
Spring compensating gear	Engine oil or soft grease
Brake gear	Engine oil or soft grease
Coupled wheel boss faces	Soft grease or engine oil
	Engine oil, or water & graphite in sandy areas
Piston rod & valve spindle packing	
	Engine oil
Bogie centres	Engine oil
Bissel spring saddles & friction plates	
	Engine oil
Grate shaking donkey cylinder	
	Cylinder oil
Miscellaneous lubrication, such as reversing-gear, rods, regulator rods etc	
	Engine oil
Cushion buffers	Engine oil

The methods of feeding the various types of lubricant to the different parts are as follows:

Cylinder oil for lubricating valves and pistons is usually supplied from a hydrostatic lubricator in the cab. Over 200 of the latest locomotives placed in service have been equipped with mechanical lubricators, and a brief description of how these work and the oil distributor system on the engine is given below, after the description of the hydrostatic lubricator and its associated fittings. On these locomotives a separate small lubricator is mounted on the mechanical stoker engine to lubricate it. The type of hydrostatic lubricator usually fitted to locomotives is the 'Detroit' lubricator, although some engines are fitted with Wakefield 'Eureka' lubricators. Either type may have two, four or five separate feeds. The principle on which these hydrostatic lubricators work is the same for both types, so that while there are differences in detailed design, it is only necessary to describe the more commonly fitted 'Detroit' lubricator.

A column of water exerts pressure due to its weight on the oil in the reservoir of the lubricator, thus forcing the oil past the regulating valves. Each drop of oil is then carried by a current of steam through a pipe to the point of delivery. **Fig 73** shows a diagrammatic view of a Detroit lubricator.

Steam at full pressure from the boiler enters the lubricator at **A**, and some of it condenses, thus filling the condenser to the point **C**. The condenser is connected to the oil reservoir by the water passage **B**, which is provided with a water valve **G**. If this valve is open, the water will fill all the space in the reservoir not already occupied by oil, and as oil is lighter than water, it will float on top of the water. The weight of the column of water measured from the point **C** to the point **E** acts underneath the body of oil in the reservoir, thus forcing the oil through the oil passage **J** and past the regulating valve **F**. This valve allows the oil to pass drop by drop into the sight feed chamber, which is kept full of water from the equalizing passage **D**. The drops of oil float up through the water to the top of the sight feed chamber at **I**, where they are picked up by the steam flowing through the equalizing passage **D** and are carried through the delivery pipe to the point of lubrication.

The boiler pressure does not affect the working of the lubricator, as the steam pressure at **A** and **I** are equal. It is purely the weight of the column of water from **C** to **E** that forces the oil through the passages and valves, and as this weight is constant, the lubricator will work at a constant rate once it has warmed up to its normal working temperature.

A master control valve is fitted in the oil passage between the reservoir and the regulating valves, of which there is one to each feed. There are normally three positions of the master control valve, which are:

1. 'All Open' - when oil is supplied to all the regulating valves;
2. 'Pump' - when oil is supplied to the two inner regulating valves only (on a four feed lubricator);
3. 'Closed' - when all feeds are shut off.

Whenever the engine is standing for any length of time the master control valve must be moved to the 'Closed' position so as to avoid waste of oil, but it must not be forgotten that it is essential to turn it back to the 'All Open' position before actually starting.

The correct way to fill a lubricator is as follows :

1. Close master control valve.
2. Close water valve **G**.
3. Close condenser valve **H**.
4. Close lubricator steam valve on the turret.
5. Open drain valve to release any pressure in the lubricator.
6. Remove filling plug, and allow all the water in the oil reservoir to run out. If there is any oil left in the lubricator, it will start to run out of the drain valve after all the water has escaped, and the drain valve should be closed immediately the oil appears.
7. Fill up the lubricator with *Cylinder Oil*. If there is not enough oil issued to fill the lubricator completely, clean water should be put in

up to the bottom of the filling plug hole. *In no circumstances must Engine Oil be used in the lubricator.*

8. Replace the filling plug and tighten up gently. Excessive force used on the spanner will do no good, and soon damages the plug threads.

The correct way to start the lubricator is as follows:

1. Open the lubricator main steam valve on the turret fully.
2. Open the condenser valve **H** fully.
3. Open the water valve **G** about four or five turns and wait for about five minutes to ensure that the condenser fills up with water.
4. Open the master control valve.
5. Set the feed regulating valves. This is done by opening each valve about half a turn and waiting to see that all feeds are working. Each valve should then be closed, and opened again slightly and the time from the escape of one drop to the escape of the next should be taken, until the correct rate of feed is obtained.

The lubricator should be working properly at least fifteen minutes before the engine leaves the running shed, so as to make certain that the oil is reaching the steam chest and the cylinders before moving any distance.

The rate at which the oil should be fed to the steam chests and the cylinders depends on several factors, such as the type of locomotive, the speed of the train, and the size of the drops escaping through the sight feed nipples. Judgement is therefore necessary in setting a lubricator. The two essential points to remember are:

1. that the oil must last for the whole trip, but that there should not be much oil left over at the end;
2. that more oil must be fed to the steam chests than is fed to the cylinders.

The following table of feeds will serve as a guide for locomotives fitted with Detroit lubricators in good condition:

Allowance of Cylinder Oil per 100 miles	Passenger Trains Seconds per Drop		Goods Trains Seconds per Drop	
	Steam Chest	Cylinder	Steam Chest	Cylinder
1 pint	40	50	45	55
1¼ pints	35	45	40	50
1½ pints	30	40	35	45
1¾ pints	25	35	30	40
2 pints	20	30	25	35
2¼ pints	15	25	20	30

Where mechanical stoker equipment is fitted to locomotives with hydrostatic lubricators an extra oil allowance of ¾ pint per 100 miles of *cylinder oil* is allowed. The hydrostatic feed for the stoker engine must be set to give one drop of oil every 20 seconds.

When a Wakefield 'Eureka' lubricator is fitted, the seconds per drop should be doubled (approximately) as this lubricator gives drops larger than those given by the Detroit lubricator.

Some old locomotives using saturated steam have feeds to the steam chests only, so that the rate of feed will then be faster.

On certain articulated locomotives, one or more of the feeds are split into two, and where this is done care must be taken to double the rate of feed which would be given to a single connection.

The steam cylinders of mechanical stoker engines are supplied with cylinder oil from the hydrostatic lubricator. The oil must be fed at the rate of three drops per minute, and the feed must be set while the stoker is in full operation, as the oil feed to the stoker engine is shut off when the stoker operating valve is closed.

The feeds to the steam chests of the locomotive are usually connected to the main steam pipes close to the steam chests. Inside each steam pipe is an atomiser, which breaks up the oil into small particles. These particles are carried by the steam to all the rubbing surfaces of the valves and the pistons, and if sufficient oil is fed in this way proper lubrication of the front end is ensured while the engine is steaming. The lubricating effect of the oil supplied direct to the cylinders while the engine is steaming is very, as most of this oil is carried away by the exhaust steam before it has been deposited on the rubbing surfaces, and it is therefore most important not to rely on the cylinder feeds for lubrication while steaming. When a locomotive is drifting, not much of the oil entering the steam pipes finds its way into the cylinders, which is why a separate feed to each cylinder is provided on most locomotives.

The proper use of drifting valves, as mentioned in **Sections 5** and **12**, greatly assists lubrication of the front end while drifting. In the first place the small supply of steam carries some of the atomised oil from the steam pipes into the cylinders. In the second place much less air is drawn into the steam chests and cylinders, so that there is less chance for the oil to oxidise and form deposits of carbon. If the drifting valve is not used, a thin blue smoke may often be seen coming out of the chimney, caused by the oxidation or partial burning of the lubricating oil.

In order that the oil from the lubricator shall flow at a more or less constant rate into the steam pipes and the cylinders against a varying steam pressure, choke valves are fitted in the delivery pipes as near to the steam pipes and the cylinders as possible. These valves are made with a hole 1/16 inch diameter, and help to atomise the oil. Provided the lubricator main steam valve on the turret and the condenser valve are kept fully open, the pressure in the delivery pipes will always be slightly higher than that in the steam pipes, even when the regulator is fully open, so that the oil will always flow in the right direction. If the hole in the choke valve gets too large through wear, the valve should be reversed until that side also gets too large, the maximum diameter allowed being 3/32 inch. If the hole becomes larger than this, the lubricator will feed a good deal faster than it should when the engine is drifting, and considerable waste of oil will occur.

Fig 74 shows a choke valve.

The lubricator should be shut off about 15 minutes before the locomotive is stabled or handed over to shed staff. The correct way to do this is as follows:

1. Close all the feed regulating valves;
2. Close master control valve;
3. Close water valve;
4. After waiting for fifteen minutes close the condenser valve and the steam valve on the turret.

The reason for waiting for fifteen minutes is to allow the oil in the delivery pipes to be cleared into the steam pipes and the cylinders. If this were not done, the oil would blow back into the sight feed chambers and foul the glasses as soon as the engine was moved under its own steam in the shed with the lubricator shut off.

The sight feed chambers should always be blown out through the vents at least once every trip. This helps to keep the glasses clean and prevents undue accumulation of salts and other dirt in the chambers. The lubricator itself should be thoroughly blown out at least once a week.

It is most important to remember certain points about the use of the hydrostatic lubricator. These have been proved by extensive practical tests and they must not be thought to be purely theoretical.

1. The main steam valve and the condenser valve must be kept fully open, otherwise there will be a lower pressure in the lubricator and in the delivery pipes than there is in the steam pipes and the cylinders, thus preventing the oil from feeding properly while the engine is steaming.
2. More oil must be fed to the steam chests than to the cylinders.

3. Only cylinder oil, and water if necessary, must be put into the lubricator.
4. The driver is responsible for seeing that the lubricator works correctly.
5. The drifting valve must be used where fitted. When no drifting valve is provided it is always best to keep the regulator slightly open while drifting.

It is sometimes found that after the lubricator has been filled one or more of the feeds will not work. The reason for this is almost always an air lock in one of the passages, and the way to remove this bubble of air is to open the regulating valve and the vent on the feed concerned, until the oil appears, and then shut the vent.

A blocked up choke valve will prevent the oil from getting into the steam pipe or the cylinder, as the case may be, and the first indication will usually be that the feed concerned works very slowly and may even stop working. If allowed to continue for any length of time the sight feed glass will become black with oil, and the delivery pipe will usually cool down. In extreme cases, particularly with the feed to the steam pipe, the front end will start to grunt, which is a positive indication of lack of lubrication. To clear the choke valve, the first method to try is to shut off the lubricator and open the vent on the feed concerned. The obstruction will often be blown clear if the regulator is opened. Failing this, the train should be stopped at the first station or interloop and the lubricator shut off. The vent on the choke valve casing should then be opened, and the regulator be rapidly opened and closed, when the steam pressure will usually blow out the obstruction. If neither of these methods works, the choke valve must be removed and cleaned. A strand of wire from the whistle cord is effective for this purpose.

The usual indication of a worn choke valve is that the lubricator will feed much faster while the regulator is closed than when it is open, and the remedy is to reverse the choke valve.

When a train engine is required to do shunting, the rate of working of all the feeds can be reduced by moving the master control valve to a point part way between the 'All Open' and the 'Pump' positions.

Some locomotives are fitted with a transfer filler for filling up the lubricator while running. A small pipe connects the condenser on the lubricator to the filler, and a larger pipe runs up from the filler to the oil reservoir of the lubricator. A small steam pipe gives the means of heating the oil in the transfer filler. The method of working is as follows. First close all valves and drain the transfer filler, and then put in the cylinder oil, topping up if necessary with clean water to a level about one inch below the bottom of the

filling plug, and turn on the steam to warm the oil thoroughly. Then open the valve on the small water pipe from the condenser, and after a minute or two open the valve on the larger (oil) pipe to the reservoir. The oil in the transfer filler will then be forced up into the lubricator by the weight of the water in the small pipe. **Fig 75** shows the pipe arrangements.

Mechanical Lubrication

Engines fitted with mechanical lubrication have a *mechanical lubricator* mounted on the frame in front of one of the expansion links. The outside trunnion of the expansion link has a crank arm fitted to it and the end of this is coupled to the lubricator driving arm by means of a long rod. This driving arm is attached to a ratchet housing on the end of the lubricator shaft. The ratchet grips in one direction only so that when the locomotive is in motion and the rod moves backwards and forwards the lubricator shaft is made to rotate slowly in one direction. The amount of lubrication provided is, therefore, proportional to the speed and distance travelled by the engine.

The *lubricator* is essentially a box containing a number of pump units and associated outlets from where the oil is led to the parts to be lubricated. The lubricator shaft has cams on it which cause the pump plungers to move up and down and thus pump oil when the shaft rotates. A separate adjustment is provided on each pump unit inside the lubricator to adjust the amount of oil delivered per stroke of the pump.

The *oil supply* for the lubricator consists of an *oil reservoir* mounted on the running board or in a pocket in the water tank or bunker in the case of Garratt type engines. The oil flows through a pipe from the reservoir into the lubricator which has a bolted oil-tight lid.

A steam supply is provided to keep the oil hot and fluid in the reservoir, connecting pipe and lubricator. The steam flows through a heating coil in the reservoir and heating passages cast in the lubricator body.

Oil level sight glasses are provided in both reservoir and lubricator so that the oil level in both can be readily seen. Due to the large capacity of the reservoir the locomotive can work for a lengthy period before a replenishment is necessary.

Four of the pump units are arranged to supply oil direct to the valves and pistons. The oil flows from each of them to a *high pressure terminal check valve.* This consists of a spring-loaded valve set at a pressure slightly above the maximum boiler pressure and prevents steam and water blowing back into the lubricator and also ensures that the connecting pipe remains full of oil. As the pumps have non-return delivery valves the oil in the pipe remains

under pressure and oil is thus delivered from the valve as soon as the pump plunger starts its pumping stroke.

The high pressure terminal check valves are mounted directly on top of the *oil atomisers* so that the oil delivered from the former is fed directly into the latter. Here it is mixed with saturated steam from the boiler flowing through an atomiser nozzle and emerges from this in a finely atomised state.

The mixture of atomised oil and steam is now led by a pipe to the conventional atomiser mounted in the steam pipe leading to the steam chest for valve lubrication and to a nipple in the cylinder casting and liner for piston lubrication.

The remaining pumps in the lubricator supply oil for lubricating other working parts of the locomotive, viz., slide-bars, piston rods, valve crossheads, valve spindles and tail rods, shoes and wedges and die-blocks. In these cases the oil is first delivered to 2- or 4-way dividers which discharge it equally into 2 or 4 different outlets. Pipes from these outlets then deliver the oil to the various points to be lubricated. A *low pressure* terminal check valve is placed at the end of each of these pipes. This is a lightly loaded valve which is opened due to the pressure in the oil as it is being pumped and which prevents the oil in the pipe draining out. Oil is thus delivered immediately the engine commences to move.

No low pressure terminal check valves are fitted in the case of the die-blocks as the oil cannot leak away here easily. The oil is led from the frame by means of a flexible rubber pipe to the reversing shaft arm and from there by other flexible pipes to the end of the radius rod and through, drilled passages in it to the die-block pin and so into the die-block bush and onto its rubbing surfaces.

Shoes and wedges are lubricated either through direct connections or from four-way dividers mounted on 'cannon' type roller bearing axle, boxes on the coupled wheel axles. The oil supply is taken to these dividers by means of flexible rubber pipes from a point on the frame. The various pumps are set to deliver the correct quantities of oil so that the *driver's responsibility* is to see that the mechanical lubricator is working, that there is an adequate supply of oil in the reservoir and that each point to be lubricated is actually receiving a supply of oil. He must lubricate the valve motion as usual. It will be realized that on these engines the items lubricated, as mentioned above, will receive valve oil and not axle oil as used on conventionally equipped engines.

The advantages of mechanical lubrication on engines is that the working parts receive a constant and regulated supply of lubricant which is proportional to the speed of the engine and to the distance travelled. This is

an effective means of reducing the wear of these working parts and of giving a very free running engine.

The driver has no adjustments to make but must ensure that the equipment is functioning correctly and book any defects or suspected defects he may come across while examining or working the engine.

The usual method of feeding engine oil to bearings and other rubbing surfaces is by means of a wick feed which draws the oil from an oil well and delivers it down a small syphon pipe to the bearing. The wick used is in the form of a trimming made of strands of wool known as worsted, held in position with twisted copper wire.

Five different types of trimming are used, and each must be made to fit the individual syphon pipe and oil well. The standard types are as follows:

Tail Trimming. This type of trimming is used where the oil well or oil cup does not move, as on the following parts:

a) Engine coupled wheel axle-box horn cheeks
b) Engine bogie and pony axle-boxes
c) Piston rod and valve spindle auxiliary oil cups
d) Valve spindle crossheads
e) Slide bars
f) Expansion link trunnions
g) Bogie centre oil cups
h) All other fixed oil cups

Fig 76 shows a tail trimming.

Sufficient strands of worsted must be used so that the trimming will be a fairly easy fit in the syphon pipe. The amount of oil delivered to the bearing surface is controlled by the number of strands or 'suckers' dipping into the oil in the well or cup. More strands are required in cold weather than in hot weather, as the oil is thicker when cold, and does not then syphon up the worsted so quickly. If more suckers are used than is necessary, oil will be wasted, so that after the trimming is pushed home into the syphon pipe, any suckers not required must be cut off flush with the top of the syphon pipe.

A guide to the number of suckers required is given below, but it must be remembered that the number may have to be altered to suit individual cases, apart from changing weather conditions.

Coupled axle journals (oil lubricated)	8
Horn cheeks	4
Bogie Journals	8
Bogie centres and swing links	4

Expansion link trunnions	4
Slide bars	8
Piston rods and valve spindles	4

Horn Trimming. This type of trimming is used in the oil wells of semi-rotary and reciprocating parts, such as union links, expansion links and die blocks. **Fig 77** shows a sketch of a horn trimming.

The plug portion of the trimming should be made so that fairly light pressure will push it into the syphon pipe. The worsted should be wound fairly loosely round the horns so that the oil can syphon freely as it is splashed from the oil well against the horns.

Plug Trimming. This type of trimming is shown in **Fig 78**, and is used on all rotating parts, such as big end and coupling rod bushes when they are oil lubricated, coupling rod knuckle joints, and eccentric crank pins on Walschaerts valve gear. The trimming should be a fairly firm fit in the syphon pipe, depending largely on the weather conditions, as a tighter fit is required in hot weather than in cold.

The distance from the bottom of the copper wire loop to the top of the worsted should be about ½ inch to allow a small space for oil to collect in the syphon pipe.

Eccentric Strap Trimming. This trimming is similar to the plug trimming, except that the wire loop is larger. It is used in the oil wells on eccentric straps of engines fitted with Stephenson link motion.

Arch Trimming. When there is a tendency for the tail trimmings on bogie, pony or coupled wheel axle-boxes to work out of the holes, two adjacent trimmings must be joined together by using one piece of copper wire for making both trimmings. When this is done the two tail trimmings joined together are known as an arch trimming.

The oil wells on all moving parts which are fitted with either horn or plug trimmings, are closed by means of cane corks screwed firmly into the tops of the oil wells. These corks have very fine holes in them, sufficient to admit air to the oil well to replace the oil used but too small to allow the oil to escape. It is essential for enginemen to see that all the cane corks are in position, and that any which become lost are immediately replaced.

Trimmings must be clean if they are to work properly, and a trimming which has become soaked with water is useless. All trimmings must be examined by the shed lubrication staff at each washout, and must be renewed if they are in any way defective and in addition every locomotive must be retrimmed once

every six months, or at sheds where the '15 M' examination is in operation, after every 15,000 miles of running. While the locomotive is in the charge of the driver, he must see that all trimmings are in position and functioning properly.

Tail trimmings will deliver oil continuously and regularly as long as there is any oil left in the well or cup, and therefore if a locomotive is kept standing for any length of time, and particularly when it is stabled, all the tail trimmings which can conveniently be reached should be taken out of the syphon pipes. As the trimmings in the tops of axle-boxes are difficult to reach they should be left alone. Horn trimmings and plug trimmings need not be removed.

Soft grease is supplied to bearing surfaces through button-headed nipples, and a grease gun producing a very high pressure is used. It is essential that the grease nipples be wiped *clean* before the grease gun is used, to prevent dirt being forced into the bearing. Grease guns need careful handling, and must not be placed anywhere near the boiler, as the heat damages the leather washers in the connections. Grease guns must be repaired as soon as they show signs of leakage or other defects.

On locomotives where the valve spindle crosshead guides are lubricated with soft grease, a continuous slow feed is essential. As this cannot be given by the driver with a grease gun, automatic lubricators are fitted, which are worked by means of a spring. These lubricators are provided with grease nipples for filling them from the soft grease gun. It is essential to see that the small cock on the automatic lubricator is opened while the engine is in use, and is closed when it is stabled, so as to avoid loss of grease.

Hard grease is supplied to bearings in two ways. Coupling rod bushes and connecting rod big end bushes are lubricated through nipples by means of a hard grease gun. The standard nipple now rapidly replacing all other designs is the bayonet nipple, and the grease gun is made to suit it. As in the case of soft grease nipples, the bayonet nipples must be cleaned before the grease gun is used, and a piece of waste damped with paraffin is the best for this purpose. In addition to preventing dirt from being forced into the bearing, the cleaning of the nipples avoids damage to the socket of the grease gun.

All bushes lubricated with hard grease are of the floating type, so designed that they are free to rotate inside a steel bush in the rod, and also to turn over the outside of the crank pin. These floating bushes are made of a special brass, and a large number of holes are drilled all over the surface of the bushes. The grease forced in by the grease gun fills all these holes, which then act as reservoirs for the grease.

The arrangement of the big end and driving bushes on the driving crank pin is shown in **Fig 79**. The other coupling rod bushes are similar, except that there is, of course, only one bush on each crank pin.

Coupled wheel axle-boxes are supplied with grease from a grease pad, shaped to fit the axle. Between the pad and the axle is a perforated plate, also shaped to fit the axle accurately, and the pad and the perforated plate are held against the axle by one or two coil springs. The springs rest on the bottom of the keep, passing through holes in the bottom of the container, and at the top act on a follower plate immediately underneath the grease pad. In the case of engines with overhung springs, two light chains hang from the follower plate through holes in the bottom of the grease container, to indicate the thickness of the grease pad. The more links of the chain that can be seen, the thicker is the pad, unless, of course, the pad has stuck and the perforated plate is not touching the axle. In such a case the axle-box will not run hot quickly. Engines with underslung springs are not fitted with chains as there is not sufficient space between the keep and the horn stay for them to be of much use. They are, however, fitted to the driving axle boxes of engines with Stephenson link motion. Here the eccentrics are close to the axle-box and the chains assist when removing the grease pad.

The arrangement of the perforated plate, grease pad, follower plate and springs is shown in **Fig 80**.

All axle-boxes fitted with plain white-metalled bearing surfaces are lubricated with oil, and except in the 'Isothermos' axle-box the oil is supplied to the rubbing surfaces by means of soaked wool waste packed into the box below the axle journal. Where the axle-boxes are fitted outside the wheels, as on tenders, engine bissels, coaches and trucks, the soaked waste provides all the lubrication necessary. The waste must be firmly packed into the axle-box so that it touches the journal all the way from the back of the box to the front, and the loose ends of the wool at the sides of the box should be turned down away from the axle. The box is then filled up with engine oil to the level of the bottom of the square hole in the front of the box, and this hole is closed by means of an iron cover.

Where the axle-boxes are fitted between the wheels, as in the case of engine leading bogies and coupled wheels, the waste is packed into the keep of the axle-box. Extra oil cannot conveniently be added to the waste in such axle-boxes, and therefore the oil necessary to keep the waste thoroughly soaked is supplied from oil wells or cups by tail trimmings, as previously described. It must be remembered, however, that the supply of oil to the bearing surfaces comes almost entirely from the waste packing, and therefore the waste must be touching the axle journal.

Roller bearing axle-boxes are lubricated with roller bearing grease or special oil, and in no circumstances must drivers attempt to put engine oil or ordinary soft grease into these axle-boxes. Roller bearing axle-boxes must be lubricated by the shed staff, as laid down by the Chief Mechanical Engineer. Proper lubrication depends on two factors, namely (1) an adequate supply of the correct type of lubricant and (2) cleanliness. Regarding the first, it must be understood that lubricants do not normally get used up, but that they work out of the bearings and drop off. It therefore follows that only sufficient oil or grease need be supplied to ensure that the lubricating film is maintained. Flooding a bearing with oil is wasteful and normally does no good whatever, as most of the oil drops off or is thrown off quickly. A steady small supply of lubricant should be aimed at.

Concerning the second factor, it is obvious that if the lubricants used are dirty, this dirt will be carried into the bearings and will cause damage. Exactly the same thing will happen if the oil or grease passages or the grease nipples are dirty, and it is therefore absolutely essential to see that lubricants and lubricating appliances such as oil cans, grease guns, oil cups and wells and grease nipples are clean. Water must be regarded as 'dirt' where lubricants are concerned (except in the hydrostatic lubricator), as water ruins the lubricating properties of most oils and greases. Enginemen must be particularly careful to see that oil cups and oil wells are clean and do not contain water, and they must remember that oil floats on water, so that if water is present it will be *underneath* the oil and therefore difficult to see. Dirty oil wells and cups must be booked for cleaning at the running shed.

Many parts on a locomotive require very little lubrication, and are therefore provided with plain oil holes into which one or two drops of engine oil should be put at least once on every trip. This oil, in addition to lubricating them, prevents corrosion and rusting up of the parts concerned and helps greatly to keep the locomotive riding smoothly and to make it easy and comfortable to handle. Some of the parts commonly neglected, and which must receive regular lubrication are:

- Spring hangers and compensating beams
- Regulator rods and levers (multiple valve type)
- Reversing screws, nuts and levers
- Reversing rod pin joints and guide brackets
- Reversing gear handles on steam operated gears
- Firehole door pin joints and slides
- Engine brake gear
- Smokebox door hinges
- Grate shaker and drop grate shafts
- Vacuum cylinder trunnions

On some locomotives certain of the parts mentioned are lubricated by means of soft grease instead of oil, and these parts must receive equal care. It must not be thought that soft grease will stay in a small bearing indefinitely.

Lubricators supplying a special grease are fitted to the rails on certain sections of line where the curvature is severe. Each wheel passing the lubricator forces a small amount of this grease out against the wheel flange and in this way the rails and the flanges along the whole train are lubricated. Rail and flange lubricators have been found to be most effective in reducing flange wear and side cutting of rails.

The methods of dealing with hot axle-boxes and other bearings will be described in **Section 11**, Breakdowns.

The attention of shed staff is drawn to the Lubrication Circulars issued from time to time by the Chief Mechanical Engineer.

SECTION 7

VACUUM & STEAM BRAKES
Energy of movements. Methods of pressing brake blocks against wheels. Partial vacuum. Perfect vacuum. Effect of altitude. Vacuum gauge. Continuous & automatic brake. Train pipe system. Separate & combined vacuum brake cylinder. Release valves. Arrangement of brake piping on locomotives & goods & passenger stock. Ejectors principle of working.

GRESHAM & CRAVEN TYPES
Dreadnought Ejector: *Annular steam jets. Small & large ejector steam valves. Discharge tube. Application valve disc. Air clacks. Air lock chamber. Vacuum limiting valve. Actions taking place during brake applications.*
Super-Dreadnought Ejector: *Improved design. Mechanically operated valve by small ejector steam valve handle.*
S.J. Ejector: *Single (or solid) steam jet cones. Large ejector steam valve operating mechanism. Brake application valves, spring loaded train pipe isolation valve. Dead engine working ball valve & drain valve.*
S.S.J. Ejector: *Similar to S.J. ejector but divided into three parts. Method of mounting. Dead engine working. Advantages of this design.*

DAVIES & METCALFE TYPES
M. & H.C. Ejectors: *Similar to S.J. ejector. Principle of operation. Steam pressure regulator. Air clacks. Outer air valve. Dead engine working. Ball valve. Drain valves.*
H.T.1 Ejector: *Similar, to previous types, but of divided construction. Method of mounting. Essential difference from M. and H.C. types & dead engine working. No pressure regulator fitted. Advantages of this design.*

Method of working Vacuum Brake, 'best setting', reducing train pipe vacuum, vacuum stop alarm, air leakage into a vacuum brake system, internal leakages, long brakes, sticking pistons, steam brake.

Brake arrangements on Garratt locomotives.

Auxiliary train pipe & drivers isolation valve. Delay action valve.

VACUUM & STEAM BRAKES

Railway vehicles must be provided with brakes in order to allow the speed to be controlled, to stop a vehicle or a train of vehicles, as well as to hold them when they are standing on a gradient. The brakes consist of cast iron blocks which are pressed against the tyres of the wheels by means of levers and rods. The friction set up between the brake blocks and the wheels, together with the adhesion or frictional grip between the wheels and the rails gives the necessary braking effect.

It must be realized that a moving train possesses a large amount of energy, which is proportional to the weight of the train and to the square of its speed. This means that if the weight of the train is doubled and its speed remains constant, the energy is doubled, but if its speed is doubled while the weight remains constant, there is four times as much energy. This energy of movement cannot be destroyed, but must be absorbed by converting it into heat at the brake blocks.

Careful testing has proved conclusively that if the grip of the brake blocks on the tyres is severe enough to lock the wheels and make them skid along the rails, the braking effect on the train or vehicle is considerably reduced. The maximum braking effect is obtained just before the wheels start to skid.

Three methods of pressing the brake blocks against the wheels are in use on the S.A. Railways. They are:

1. By means of a hand lever, or a screw turned by hand. All locomotives are fitted with a screw hand brake on the tender, or on one of the units of an articulated engine. All goods vehicles and all guards' vans, passenger and goods, as well as dining cars, private saloons and coaches fitted with roller bearings are provided with hand brakes.
2. By means of steam pressure from the locomotive boiler. Steam brakes are used only on locomotives.
3. By means of the pressure of the atmosphere which becomes available when a partial vacuum is destroyed. All goods vehicles and coaches on the S.A. Railways, with the exception of a small number of obsolete trucks used exclusively in harbour and workshop areas, are fitted with vacuum brakes. All locomotive tenders, as well as many articulated locomotives and certain of the most modern ordinary locomotives are also fitted with vacuum brakes.

A perfect vacuum is formed in an enclosed space when all the air together with any other gases or vapours have been completely withdrawn, leaving *nothing* behind. This is a condition which can never be completely attained in practice, but there is no great difficulty in withdrawing a considerable proportion of the air from an enclosed space, thus creating a *partial* vacuum.

If a perfect vacuum were created in a closed vessel, the atmosphere would exert a pressure on the outside of the vessel amounting to 14.7 lb per square inch under normal conditions at sea level. This pressure is sufficient to support a column of mercury 30 inches high, or in other words a column of mercury of one square inch cross-sectional area and 30 inches high weighs 14.7 lb. The measurement of the degree of vacuum created in any enclosed space is usually given in inches of mercury, 30 inches representing a perfect vacuum and no inches no vacuum at all, or atmospheric pressure. If the atmospheric pressure at sea level be taken as approximately 15 lb per square

inch, for easy calculation, it follows that every inch of mercury measuring a partial vacuum represents a pressure of ½ lb per square inch acting on the outside surface of the enclosing vessel. For example, a vacuum of 20 inches of mercury represents a pressure on the vessel of 10 lb per square inch, which is the difference in the pressures inside and outside the vessel.

The pressure of the atmosphere decreases by approximately ½ lb per square inch for every 1,000 feet rise above sea level, so that at 6,000 feet the pressure available on the outside of a vessel enclosing a perfect vacuum will be 12 lb per square inch instead of almost 15 lb per square inch. At 6,000 feet, therefore, the atmosphere will support a column of mercury 24 inches high, and 24 inches of mercury represents a perfect vacuum at 6,000 feet above sea level. It must be understood, however, that a vacuum of 20 inches of mercury always represents a pressure on the outside of the enclosing vessel of 10 lb per square inch.

While accurate measurements of the degree of vacuum are made by means of a column of mercury, this system is not suitable for use on a locomotive, and a mechanical type of vacuum gauge is used. The gauge is in principle exactly the same as the steam pressure gauge which is described in **Section 4**. It should be noted that in a vacuum gauge the spring tube tends to bend more the higher the vacuum, and the scale over which the pointer works is marked off in inches of mercury, from 0 to 30. All guards' vans, both passenger and goods, as well as most private saloons are fitted with a single vacuum gauge. Nearly all locomotives are fitted with a ‘duplex’ vacuum gauge, which consists of two separate spring tubes together with their quadrants and pointers, and is actually two independent gauges inside one casing.

The vacuum brake as used on the S.A.R., and on many railways in other parts of the world is known as ‘continuous and automatic’. By continuous is meant that the brakes of all the vehicles comprising a train are under the direct control of the driver and to some extent of the guard, and that the brakes are applied or released more or less at the same time on every vehicle. By automatic is meant that should the train become accidentally divided, or should the piping controlling the brakes become damaged, the brakes will be automatically applied.

Every vehicle on the train is provided with one or more brake cylinders which are coupled to the ‘train pipe’ by means of flexible branch pipe hoses. The train pipe is a steel pipe which runs the full length of every vehicle, and at each end of the vehicle the pipe is fitted with a flexible hose having a special coupling at its open end. The hoses on each vehicle are coupled to the hoses on the vehicles in front of and behind it, until the pipes throughout the train are made continuous. The flexible pipes at the leading end of the locomotive and at the rear of the guard's van are closed by placing them on the dummies

provided for that purpose, so that the whole pipe system along the train, together with the brake cylinders, forms an enclosed space. The necessary partial vacuum in the pipe system and the cylinders is created by means, of a steam ejector on a steam locomotive or by an exhauster on an electric locomotive or a motor coach.

The brake is applied by admitting air to the train pipe, and thus reducing the degree of vacuum in the pipe. The more the vacuum is reduced, the harder the brakes will be applied. It must be clearly under stood that if no vacuum is created, there will be no vacuum to reduce, and the brakes will not work.

Two types of vacuum brake cylinder are in use on the S.A. Railways, and each of these is made in four sizes (15, 18, 21 and 24 in. Diameter) to suit vehicles with different weights. Both types of cylinder work in exactly the same manner, and therefore only one, the separate cylinder, will be described fully.

The cylinder is an iron casting, with the lower cover formed in one piece with the barrel. The upper cover is also made of cast iron and is provided with lugs for bolting it down to the cylinder barrel, an airtight joint being formed by means of a rubber joint ring. The piston is a casting of pan shape, which fits loosely inside the cylinder. An airtight joint between the piston and the. cylinder is obtained by using a rubber ring which rolls between the piston and the cylinder wall with little resistance as the piston moves up or down in the, cylinder. This ring is known as the rolling ring, and when the piston is at the bottom of the cylinder the ring lies in a groove at the top of the piston. This relieves the pressure on the rolling ring while the brakes are off, and allows the piston to get a free start when the brakes are applied. A piston rod is screwed into the lower side of the piston, and projects through a bush in the lower cylinder cover. An airtight joint is formed by a rubber neck ring held in position by a small gland. The neck ring is so made that it grips the piston rod firmly while there is a vacuum in the train pipe and in the cylinder, but is a fairly loose fit when the vacuum is destroyed. The piston rod is coated with brass to allow it to slide freely through the neck ring, and to prevent corrosion, as no oil or other lubricant can be used on it.

A slotted hole is formed in the lower end of the piston rod, and the pin coupled to the brake shaft lever passes through this hole. The cylinder is supported on two trunnions fastened to the barrel and resting in brackets secured to the underframe of the vehicle. The cylinder must be free to swing on these trunnions to a small extent. A separate vacuum chamber is provided, which is permanently coupled to the top of the cylinder, above the piston.

The brakes are applied by admitting air into the train pipe and into the cylinder *below* the piston, thus causing the piston to rise in the cylinder. The piston rod pulls on the lever attached to the brake shaft, and the movement is

transmitted to the brake blocks by further levers and rods. **Fig 81** shows the arrangement of a separate vacuum cylinder.

It is essential to remember that the force which lifts the piston and applies the brakes is the result of the *difference of pressure* below and above the piston. If the pressures are equal, the piston will fall to the bottom of the cylinder under its own weight. As the pressure below the piston is never more than atmospheric pressure, it follows that in order to have the necessary. difference to lift the piston, the pressure *above* it must be much less than that of the atmosphere. In other words there must be a partial vacuum above the piston, and this vacuum *must be maintained* if the brakes are to continue to work. As it is impossible to ensure that there is absolutely no leakage into the space above the piston, some means must be provided to create the necessary vacuum in this space.

This is done by fitting, a non-return valve consisting of a small ball and a suitable seating at the bottom of the cylinder. The flexible hose or branch pipe connecting the vacuum cylinder to the train pipe is coupled to the casing round the ball valve, which is so arranged that a passage to the bottom of the cylinder is always connected direct to the branch pipe, while the ball valve seals the passage to the top. of the cylinder and the upper side of the piston and to the vacuum chamber.

When air is being withdrawn by the ejector and vacuum is being created, air will flow freely out of the bottom of the cylinder into the branch pipe and the train pipe thus releasing the brake, while air from the top of the cylinder and from the vacuum chamber will lift the ball valve off its seat and will also flow out into the branch pipe. Vacuum is thus also created above the piston but due to the weight of the ball, it will be slightly less than that below the piston. This results in a small downward load on the piston which helps to push it down when the brakes are released, and also to prevent the creep of the roller ring on the piston.

When air is admitted to the train pipe, it will flow through the branch pipe and the release valve casing and directly into the bottom of the cylinder below the piston. The ball valve now returns to its seat and cuts off communication between the branch pipe and the top of the cylinder above the piston. The vacuum previously created above the piston is thus maintained, and the necessary difference of pressure is available to lift the piston and apply the brakes. The brakes will not, however, remain applied indefinitely, as there is always a certain amount of leakage past the piston rod cap, the ball valve and the rolling ring, as well as into the vacuum chamber and its connections, and it is therefore necessary on long descending gradients to recreate vacuum throughout the train from time to time. It will be seen that any leakage into

the space above the piston (including the vacuum chamber) will gradually reduce the difference in pressure available to keep the brakes applied.

The *chamber* is provided so that a large volume is available, and therefore the brakes will not leak off rapidly, but it does not prevent them from leaking off in time.

The other type of vacuum cylinder previously mentioned, known as the combined cylinder, has. a chamber fitted around it, instead of an independent vacuum chamber mounted on the underframe of the vehicle. This chamber forms the top cover of the cylinder, and extends down the sides of the barrel, being closed level with the bottom cover, and the ball valve casing is then made with only one branch, so that the valve is known as a single branch ball valve. It works in exactly the same manner as the double branch ball valve fitted to the separate cylinder, allowing air to be withdrawn from the top of the cylinder and from the vacuum chamber, but preventing air from being admitted to these parts when the brake is applied.

Fig 82 shows the arrangement of a combined cylinder.

Apart from helping to prevent the brakes from leaking off quickly, the vacuum chamber serves another useful purpose. As the vacuum created above the piston is not a perfect one, it follows that some air is left behind, and, although this air is at a very low pressure, it is nevertheless compressed to some extent as the piston rises when the brake is applied. This compressing action raises the pressure of the air left above the piston, thus reducing the difference of pressure which applies the brakes. A large chamber connected to the top of the cylinder greatly reduces the effect of the compression of the low pressure air left above the piston and in the chamber. This is particularly important if the adjustment of the brake gear is bad and the piston has to travel a long way up the cylinder to make the brake blocks press against the wheels.

When a vehicle is put off a train, or when a train is broken up in a yard, the brakes on all the vehicles concerned are, of course, fully applied, as the vacuum hose pipes between the vehicles must be uncoupled. To release the brakes for shunting, purposes, the pressure above the pistons in the vacuum cylinders must be made equal to the pressure below them, and to do this air is admitted to the upper part of the cylinders and to the vacuum chambers. This is done by moving the ball valve off its seat, and in effect making the brakes leak off rapidly. To obtain this effect it is necessary to have one of the flexible hoses off its dummy so that sufficient air may enter the train pipe to fill up the top portion of the cylinder and the vacuum chamber.

The release valve, which is combined with the ball valve, is shown in **Fig 83**.

It will be seen that a cage surrounds the ball, and when it is pulled outwards by the release wire attached to the lever, it forces the ball off its seat. The space between the cage and the ball valve casing is sealed by means of a rubber diaphragm, so that as soon as vacuum is created in the train pipe, the branch pipe and the ball valve casing, the air pressure acting on the outside of the diaphragm forces the cage back into its normal position, so that the ball valve will work in the ordinary way. The release wires on goods vehicles are easily seen, but on passenger coaches various fittings such as battery boxes and water tanks often make the release wires difficult to find, particularly at night. For this reason is usual to paint a white star on the outside of the black underframe of a passenger coach, immediately above the point at which the release wire is tied to the underframe.

The vacuum cylinders on tenders and on locomotives (when fitted) are similar to those on goods and passenger stock, but there are certain points of difference. In the first place, they are always of the separate type, with independent vacuum chambers. Secondly the cylinders on locomotives and on tenders are not fitted with the normal type of release valve shown in **Fig 83**, although a ball valve is used. Where there is no vacuum brake on the locomotive itself, the top portion of the tender vacuum cylinder or cylinders, together with the vacuum chamber, is connected directly to the ejector, so that a vacuum is always maintained above the pistons as long as the ejector is working. A release valve is fitted just below the ejector on the 'chamber pipe' connecting the vacuum chamber and the tops of the cylinders to the ejector. When the locomotive itself is fitted with vacuum cylinders, the ejector is connected through the ball valve casings to the tops of these cylinders and to their vacuum chamber, and the tender cylinders function in the same way as those on a truck, except that a separate release valve is fitted within easy reach of the footplate. One side of the duplex vacuum gauge (marked 'Vacuum Chamber') is connected direct to the chamber pipe, while the other side is connected to the train pipe. When the brake is applied, the difference in the readings on the two sides of the duplex gauge shows the extent to which the brake is applied.

When a locomotive is coupled to a train, and the vacuum hoses are connected between every vehicle, and placed on the dummies in front of the locomotive and behind the van, the ejector will create a vacuum throughout the train. The ball valves on the vacuum cylinders will all open, and the same degree of vacuum will be created above and below each piston. This releases the brakes if they had previously been applied, and makes the brakes available for use when required.

It must again be emphasized that until a vacuum has been created above and below the pistons, the vacuum brakes are useless.

EJECTORS

A number of types of vacuum ejector are in use on the S.A.R., some of which are made by Gresham & Craven Ltd., and some by Davies & Metcalfe Ltd. Most of these are combination ejectors, with the air extracting portion and the brake application valve combined in one fitting, but the most modern types have the air extraction and application portions separate. On the S.A.R., the ejector is always mounted on a bracket on the right hand side of the firebox outer back plate, inside the cab, so that it is within easy reach of the driver.

All ejectors work on the same principle. Steam is passed through a cone of 'convergent-divergent' shape, so designed that the steam is expanded and leaves the discharge end of the cone at an extremely high speed, and at a pressure well below that of the atmosphere. A chamber round the cone is connected to the train pipe, and the air in this chamber is entrained by the jet of steam and driven through another cone into an exhaust pipe. The low pressure of the jet of steam issuing from the steam cone as well as its very high speed draws the air rapidly from the train pipe.

All the types of ejector in use incorporate two, and in one type three, ejectors in the one instrument. The small ejector is provided to release the brakes slowly, and to maintain the vacuum in the train pipe by overcoming the leakage which inevitably occurs at the various points. This small ejector uses only a small amount of steam. The large ejector is provided to release the brakes rapidly when required. When the engine is running the small ejector is kept working all the time, but the large ejector is only used occasionally. The small and the large ejectors are independently controlled.

GRESHAM & CRAVEN - 4 TYPES

THE 'DREADNOUGHT' EJECTOR

The 'Dreadnought' ejector is shown diagrammatically in **Fig 84**. It should be imagined that the ejector has been split in two and folded open, so that the portion on the left hand side of the dotted line represents the left hand half of the ejector, where the cones are fitted, while the portion on the right hand side shows the right hand half of the ejector. Each half is then sectioned to show the internal construction.

The steam jets used for both the large and the small ejectors are of the annular or ring type, and are formed by leading the steam through the space between two hollow cones, one inside the other. Air coming through the inner cone is picked up by the inside surface of the hollow jet of steam, while additional air is entrained round the outside of the steam jet after it leaves the cones. This has been found to be both effective and economical.

The steam supply for both the large and the small ejectors comes through a pipe from a valve on the turret, into a chamber in the ejector casting in which the large and the small ejector steam valves are situated. When the small ejector steam valve is opened, the steam flows into a passage and between the two hollow cones, the inner one being known as the 'cone' and the outer one the 'steam guide'. It leaves this opening at a low pressure and at a very high speed, and passes into the discharge tube and finally the exhaust pipe, creating a vacuum behind and inside the cone and in the secondary passage just in front of the cone and the steam guide. The air in the train pipe is at a higher pressure than that now left in the ejector casing, so it flows up from the train pipe, through passages provided in the application valve disc, and lifts the main air clack. The air then enters the air lock chamber, and lifts the small ejector air clack and passes along the passage to the back of the cone and also into the secondary passage. It is picked up by the hollow steam jet from both these places and is driven through the *discharge tube* where its speed is reduced and its pressure is increased to slightly above atmospheric pressure. The mixture of steam and air then flows along the exhaust pipe, which is normally fitted outside the boiler barrel on the right hand side. The exhaust pipe is led into the smokebox, and is coupled to a hollow ring formed in the blast pipe cap, which has a number of holes drilled in the top surface. The steam and air escape from these holes, and out of the chimney. The ejector exhaust ring is formed around the blower ring in the blast pipe cap, and the holes are immediately outside the blower holes.

At the same time as air is being drawn out of the train pipe, it is also being drawn through the chamber pipe from the tender or the engine vacuum chamber and the upper parts of the tender or the engine vacuum cylinders. On its way to the ejector it passes the release valve, which is fitted with a small clack valve.

The large ejector steam valve is opened by means of a cam mounted on the spindle which carries the application valve disc. This spindle passes through the body of the ejector, and when the application valve handle is pushed forward to the 'off' position, the cam lifts the large ejector steam valve off its seat. Steam then enters a passage leading to the outside of the large ejector cone, and passes through the space between the cone and the steam guide, into the discharge tube and finally into the exhaust pipe, in exactly the same way as in the case of the small ejector. The large ejector is provided with a small extra steam jet in the middle of the cone to speed up the flow of air.

The air from the train pipe flows through the passages in the *application disc valve*, past the main air clack and into the air lock chamber. As there is now a vacuum behind the large ejector cone and in its secondary passage, the large ejector air clack will lift, and the air will be drawn through the cone and through the secondary passage, where it is nicked up by the steam jet and is

driven through the discharge tube to the exhaust pipe in the same way as in the case of the small ejector.

The same exhaust pipe is used for both large and small ejectors, so that if one is working and the other is not, air and steam would tend to flow back from the exhaust pipe through the ejector not in use if no clacks were fitted. This is the main reason for fitting the large and small ejector with separate clack valves. If the ejectors are both shut off while the train pipe is in a state of vacuum, the clacks prevent smokebox gases and moisture from flowing back through the ejector into the train pipe. The main air clack is provided as an additional safeguard in case either of the other clacks is defective.

At the top of the air lock chamber is the vacuum limiting valve, which is provided to limit the amount of vacuum created by the ejector, and thus maintain a reasonably uniform vacuum in the train pipe. The limiting valve is normally held closed by a spring, but if the vacuum inside the ejector body exceeds the required amount, the atmospheric pressure above the valve will open it against the action of the spring, and limit the vacuum created to whatever is desired. The valve is set to open at 18 inches of vacuum. Adjustment is made by increasing or decreasing the pressure on the spring. A small ball valve is fitted just below the limiting valve. When either ejector is working this valve is held on its seat, but when both ejectors are shut off, and if either clack does not seat correctly, the air lock chamber will no longer be in a state of vacuum, and the ball valve will drop off its seat allowing a free escape for any vapour in the chamber. This will also happen when the vacuum in the air lock chamber has dropped through normal leakage after both ejectors have been shut off for some time.

Two methods of applying the brake are provided. One is an auxiliary application valve worked by a small trigger on the main valve handle. This admits a small amount of air into the main application valve disc, and is used for light braking. The other method is to move the main application valve handle from the normal 'running position' towards the 'on' position. Air is then admitted direct into the train pipe, and the further the handle is moved, the more the ports in the disc open to admit air, while the passages to the ejector are gradually closed. When the handle is placed in the full 'on' position, the air ports are wide open, and the passages to the air lock chamber and the small ejector are entirely closed, thus preventing the ejector from drawing out, the air being admitted to apply the brakes. The small ejector can then draw air from the chamber pipe only, thus maintaining the full vacuum above the tender or the engine brake pistons.

The clack valve in the release valve casing is provided to prevent air getting into the chamber pipe and thence into the tender or the engine vacuum chambers and the tops of the vacuum cylinders when both ejectors are shut

off. This is particularly important when an engine is being hauled 'dead', as otherwise there would be no brake on the tender unless the chamber pipe were uncoupled and plugged.

The connection from the train pipe on the locomotive to the ejector is brought up more or less vertically through the cab floor. Immediately below the joint between the train pipe and the connection to the ejector a drip trap is fitted in order to prevent water from collecting in the train pipe. The drip trap is shown in **Fig 85** and is used with all types of ejector.

Any moisture finding its way into the train pipe from the ejector or from the pipes on the vehicles will collect in this trap, and as long as there is a vacuum in the train pipe the ball valve at the bottom of the trap will be held up on to its seat. As soon as the vacuum is destroyed the valve will drop, and the water will run out through the holes in the brass plug at the bottom. It is most important that these holes be kept clear so that the water will drain out freely when the vacuum is destroyed. The ball valve itself must also be kept clean, so that it will seat properly and prevent air leakage into the train pipe.

The external exhaust pipe from the ejector to the smokebox is also fitted with a drain, but in this case no valve is provided, and the drain is simply a small open pipe connected to the lowest portion of the exhaust pipe. The small pipe is led to a suitable position below the running board so that any moisture can drain away freely.

The ejector itself is provided with a drip valve, consisting of a small ball which is held against its seat as long as the ejector is working. When the ejector is shut off, the ball valve drops and allows any water which may have collected in the large ejector air passage to drain away.

THE 'SUPER-DREADNOUGHT' EJECTOR

The 'Super-Dreadnought' ejector is a development of the 'Dreadnought', and is similar in design, the large ejectors and the application valves being of the same type in both instruments. The 'Super-Dreadnought' ejector is fitted with two small ejectors, and the small ejector steam valve is so arranged that it supplies steam first to one small ejector and by further movement, to both. It is therefore possible, with a short train having very few leaks, to use only one small ejector, and thus save a fair amount of steam. With a longer train, or where the leakage along the train is considerable, both small ejectors can be used to maintain the necessary vacuum. Each small ejector is provided with a separate clack valve.

The only other difference of any importance between the two types of instrument is that the ball valve above the air lock chamber in the

'Dreadnought' is replaced by a mechanically operated valve worked from the small ejector steam valve handle. When the small ejector steam valve is shut off, the valve in the air lock chamber is opened, and the vacuum in this chamber is destroyed. This allows any vapour to escape and also prevents smokebox gases which might be drawn past leaking clack valves from reaching the train pipe.

THE 'S.J.' EJECTOR

The 'S.J.' or Solid Jet ejector is made by Gresham & Craven Ltd., and now fitted to many locomotives on the S.A. Railways. This type of ejector is fitted with single cones to produce the steam jets for the large and the small ejectors, and these jets are solid instead of being of the hollow or ring type as used in the 'Dreadnought' and 'Super Dreadnought' ejectors. The air is drawn through a passage round the cone and leading up to the discharge end of it. **Fig 86** shows a diagrammatic view of the 'S.J. ' ejector, cut through in the same manner as the 'Dreadnought' ejector shown in **Fig 84**.

Steam is supplied from a valve on the turret and enters a chamber in which both the large and the small ejector steam valves are situated. When the small ejector steam valve is opened, the steam flows through the small ejector cone, leaving it at a very high speed and a low pressure, and creating a vacuum in the chamber above the small ejector air clack. Air from the train pipe lifts the main air clack and the small ejector air clack, and after being picked up by the steam jet, is driven through the discharge tube into the exhaust pipe.

The large ejector steam valve is opened by a lifting finger mounted on the spindle of the application valve handle. When the large ejector is working the steam passing through the cone creates a vacuum above the large ejector air clack. Air from the train pipe lifts the main air clack and the large ejector air clack and is driven through the discharge tube into the exhaust pipe.

The application valve of the 'S.J.' ejector is made in two parts, an auxiliary valve and a main valve. A lifting finger is fitted to the spindle of the application valve handle, and the first movement of the handle from the 'running' position towards the 'brake on' position causes this finger to move the valve lifter and the auxiliary valve, giving slight brake applications. Further movement of the handle opens the auxiliary valve fully, when shoulders on the valve lifter come in contact with the main valve, which also lifts.

In order to prevent the small ejector from drawing air from the train pipe when a full brake application is made, the main air clack is arranged to close. This is done by a cam on the application handle spindle, opposite the air valve

lifter. The cam moves a bell crank lever which engages a sleeve fitting over a collar on the spindle of the main air clack. The actual holding down of the main air clack is through a spring which can be adjusted by a nut at the lower end. The purpose of this spring is to allow the main air clack to lift slightly if the vacuum in the chamber pipe rises too high when the brakes are fully applied. It must be remembered that the small ejector is maintaining vacuum in the chamber pipe and in the tender or the engine vacuum chambers and the upper parts of the tender or the engine vacuum cylinders all the time it is working. A second spring is fitted round the main spring and the sleeve in order to hold the parts together and to prevent chatter.

Immediately below the main air clack a vacuum limiting valve of the usual type is fitted. The ball valve for releasing vapour from the chamber under the large and the small ejector air clacks is fitted directly to the main casting, and not to the limiting valve as in the 'Dreadnought' ejector.

A release valve of the usual type is fitted to the chamber pipe just below the ejector. A small clack valve is fitted to isolate the chamber pipe when both ejectors are shut off. In addition a ball valve is provided to enable the tender or the engine brakes to work normally when both ejectors are shut off, as occurs when the engine is dead or when it is the second engine of a double-headed, combined or banked train. This ball valve is placed close to the chamber clack valve, and the passage which it normally closes runs from the train pipe portion of the ejector to the chamber pipe just below the clack valve. When both ejectors are shut off, and the ejector on another engine is creating vacuum in the train pipe, air from the tender or the engine vacuum chamber is drawn out through this ball valve, which will close as soon as air is admitted to the train pipe.

A drain ball valve is provided to drain any water which may be formed in the chamber housing the large ejector. This valve is normally held on its seat by the vacuum inside the ejector, but will open when the vacuum is destroyed.

THE S.S.J. EJECTOR
similar to S.J. Ejector, but divided into three parts

This ejector is the most modern type made by Gresham & Craven and used on the S.A.R. The way it functions is exactly the same as the S.J. and most of the constituent parts such as nozzles, air valves, steam valves, drains and limiting valve are interchangeable.

It is in three parts, one casting embodying the driver's brake application valves and main air clacks and limiting valve, another casting containing steam valves for controlling the admission of steam to the large and small

ejectors and the ejector proper consisting of a large and a small ejector mounted in a suitable casting together with air clacks.
Steam of the large and small ejectors comes from the duplex steam valve and is regulated in that valve by means of an extension rod and spindle respectively from the driver's brake valve assembly. The extension rod is spring loaded and is moved forward to open the large ejector steam valve by a cam on the spindle on which the brake handle is mounted. The arrangement is thus the same as on the S.J. ejector except that in the latter case the parts are mounted internally in the ejector. The small ejector steam valve is regulated by the spindle, the end of which is carried in a small bracket on the driver's brake application valve assembly and is operated in the normal way.

The ejector portion is joined to the brake application valve by a single pipe. The air to be exhausted passes through this pipe, the respective air clacks, out through the ejectors into discharge tubes and then through the usual exhaust pipe to the blast pipe cap. The ejector is provided with three ball drain valves to release any accumulated water and vapour in it.

The driver's brake application valve assembly is exactly the same as the corresponding portion of the S.J. ejector including the connection to the vacuum reservoirs on the engine (or tender, if the engine is not fitted with vacuum brake).

METHOD OF MOUNTING

The driver's brake application valve assembly is mounted on the back plate of the boiler in a position convenient to the driver.

The duplex steam valve is mounted on the side of the firebox in front of the cab weatherboard and as nearly as possible directly ahead of the driver's brake valve. This is to simplify mounting the steam valve control rods. Steam is supplied direct to this valve from a connection on the turret.

The ejector can be mounted in any convenient position on the boiler barrel or frame and its exhaust led away. It is coupled to the duplex steam valve with two steam pipes to lead the steam to the ejector nozzles. As mentioned before the ejector is coupled to the driver's brake application valve assembly by a single pipe.

DEAD ENGINE WORKING

In this case, the brake valve assembly does not embody a dead engine working ball valve. This means that air cannot be evacuated from the vacuum reservoirs and the tops of the vacuum brake cylinders on the engine (or tender, if no engine vacuum brake fitted). To overcome the trouble, the brake

cylinders are fitted with ball release valves instead of the plain branch pipe casting, thus allowing the air to be evacuated. It does not affect the ability of the small ejector to maintain the vacuum above the pistons under normal working conditions.

ADVANTAGES OF THIS DESIGN

This design has the advantage that all steam connections are outside thus reducing the cab temperature. The driver's brake application valve assembly is also less bulky than a combined ejector and is thus easier to mount on a crowded back plate.

Fig 86A shows a diagrammatic view of a S.S.J. ejector.

THE 'METCALFE' EJECTOR

The 'Metcalfe' ejector is made in two models (type 'M' and type 'HC') and is fitted to many locomotives on the S.A. Railways. The two types are similar. This ejector and the 'S.J.' ejector are two of the more modern standard types, and are gradually replacing the 'Dreadnought' and the 'Super-Dreadnought' ejectors.

The 'Metcalfe' ejector employs solid steam jets, and is in many ways similar to the ' S.J.'. The arrangement of the large and the small ejector cones is shown in **Fig 87**.

Air is drawn in by the jets in two places, just in front of the steam cones or nozzles, and also in front of the vacuum tube. The action of both the large and the small ejectors is therefore as follows:

Steam leaving the cone at a very high speed and at a low pressure picks up air from the primary passage, and the mixture of steam and air flows through the vacuum tube. When it leaves the vacuum tube more air is picked up from the secondary passage, and the whole mixture is then driven through the discharge tube into the exhaust pipe.

The usual clack valves are fitted, one for the large ejector, one for the small ejector and one to protect the train pipe. The small ejector steam valve has a separate handle, while the large ejector steam valve is worked by a cam mounted on the spindle of the application valve handle, as in other ejectors.

A steam pressure regulator is fitted to the large ejector, consisting of a type of needle valve which varies the amount of steam entering the large ejector cone. A pointer mounted on the pressure regulator handle moves over a scale on which various pressures are marked, and to get the best results from the

large ejector, particularly at low boiler pressures, the handle should be moved till the pointer is opposite the pressure concerned. The regulator does not affect the small ejector.

A vacuum limiting valve is fitted to the upper portion of the ejector, and a ball valve is provided to allow steam or vapour to escape when both ejectors are shut off, as in the case of the 'Dreadnought' ejector.

The brake application valve is inside the ejector casing, and the top of its spindle projects through the casing. The valve is opened by means of a cam mounted on the spindle of the operating handle. No auxiliary valve is provided on the 'Metcalfe' ejector, but the control of the main valve is sufficiently fine to give very slight brake applications when required.

In order to isolate the small ejector from the train pipe when a full brake application is made, a separate valve known as the outer air valve is provided. This is arranged on the outside of the casing and is opened against the action of a spring by a cam on the spindle of the application valve handle. The outer air valve is closed by the spring as soon as the handle is moved to the full 'on' position. When the outer air valve is closed the small ejector can draw air only from the chamber pipe, past the release valve and its protecting clack valve.

When the small ejector is working, and provided the application valve handle is not in the full 'on ' position, air is drawn from the train pipe past the main air clack, through the outer air valve and past the small ejector air clack into the primary and the secondary passages. Air is also drawn from the chamber pipe, past the clack valve and through the open small ejector clack in the same way as the air from the train pipe, but it does not pass through the outer air valve. With the application valve handle in the full 'on' position, the outer air valve is closed, and the small ejector then draws air from the chamber pipe only.

The large ejector draws air from the train pipe, past the main air clack and the large ejector air clack into the. primary and the secondary passages of the large ejector. The air drawn in by the large ejector does not pass through the outer air valve.

To provide for double heading, or a dead engine, when the ejector is out of use, a ball valve is fitted in a passage leading from the main train pipe connection to the upper side of the release valve, and below the chamber pipe clack valve, in a similar manner to that on the 'S.J.' ejector. **Fig 88** shows the arrangement of the outer air valve, the release valve and the dead engine ball valve.

Three ball valves are provided to drain any water which may collect in the ejector, and prevent it from entering the train pipe or the chamber pipe. When the ejector is working these ball valves are held on their seats, but will drop open as soon as the vacuum is destroyed.

The non-return valves used in the ejector have been referred to as 'clacks', as this is the term which has been used in the descriptions of the other three ejectors. The makers of the Metcalfe ejector use other names for these valves, but the meaning is essentially the same.

'H.T. 1' EJECTOR
similar to previous types, but of divided construction

This is the latest type of ejector made by Davies & Metcalfe and fitted to a number of SAR locomotives. With one exception (see later) it functions in exactly the same way as the 'M' and 'H.C.' types and most of the constituent parts are the same. It can be considered as being in two parts, the driver's brake application valve assembly and the steam valve and ejector assembly. These are joined by a pipe, which in this case is a casting and has two passages in it.

Steam for the large and small ejectors is supplied from valves in the ejector body and is regulated respectively by a rod linkage coupled to the brake handle and a spindle mounted on the brake valve assembly. The large ejector steam valve is lifted by a cam on a spindle mounted in the ejector body. A short arm on this spindle is connected by a rod to another arm provided on the brake handle. Moving this forward thus rotates the spindle and opens the steam valve. The small ejector valve is the usual screw-down type and is operated by the small handle on the spindle in the normal way. The ejector is provided with a ball valve drain pipe to get rid of any accumulated water. The ejectors discharge into separate discharge tubes and thence through the exhaust pipe to the blast pipe cap. No air clacks are provided in the ejector.

The driver's brake application valve assembly is the same as the corresponding portion of the 'M' or 'H.C.' combined ejectors and contains all the au clacks, limiting valve, air inlet valve, ball drain valves, etc.

As mentioned above, this valve assembly is connected to the ejector with a two chamber pipe, one leading to each ejector. The air to be exhausted by either ejector passes through the exhaust pipe to the blast pipe cap.

METHOD OF MOUNTING

Although this ejector is of divided construction, for mounting purposes it is really a single item by virtue of the fact that its two constituent parts are

rigidly connected by the cast pipe connection. The brake valve assembly portion is bolted to a bracket on the boiler back plate and the ejector to the side of the firebox in front of the cab weatherboard. Steam is supplied direct to the ejector from a connection on the turret.

ESSENTIAL DIFFERENCE BETWEEN 'M' & 'H.C.' TYPES

Instead of an outer air valve, an 'inner' air valve is provided. This is held open by means of a lever operated by a cam on the brake valve spindle when the handle is in the 'running' or 'off' positions, but is closed when the handle is placed in the 'on' position. When closed, this valve isolates the train pipe from the small ejector which can then only draw air from the chamber pipe. In addition the vacuum limiting valve opens into the space leading to the chamber pipe (and also through the inner valve when in the 'running' or 'off' positions to the train pipe) so that the chamber pipe vacuum is limited to the same maximum amount as the train pipe.

DEAD ENGINE WORKING

When the engine is worked dead, the inner valve will be open and air can thus be evacuated from the chamber pipe into the train pipe and brake power obtained on the engine. No separate ball valve is thus necessary.

Fig 88A shows a diagrammatic view of an H.T.1 ejector. This design has the advantage that all steam connections are outside the cab and its temperature is thus reduced.

WORKING OF THE VACUUM BRAKE

From the point of view of the driver the working of the vacuum brake is the same whichever type of ejector is fitted to the locomotive. After coming on duty, and as soon as sufficient steam pressure is available, both the large and the small ejectors should be tested to see that they are working properly, after which the small ejector steam valve should be moved until the 'best setting' is found. If the valve is not sufficiently wide open, the ejector will not work well, while if it is opened too much the steam will choke in the cone, and a poor vacuum will result. The best setting will give the highest vacuum with small ejector only, and it is desirable to find this setting with the boiler pressure about 20 lb per square inch below blowing off point to allow for variations in boiler pressure along the road. Once properly set, it should not be necessary to touch the small ejector again, and it should be kept working continuously.

As soon as the engine is coupled to the train, the driver should at once create vacuum, using both the large and small ejectors. As soon as the gauge shows 15 inches of vacuum the handle should be returned to the 'running' position

and the gauge should be watched to see whether the small ejector alone is capable of maintaining the vacuum created. A slight drop in vacuum will usually be seen, but the vacuum normally rises again fairly quickly. If the small ejector will maintain the vacuum satisfactorily, it shows that there are no serious leaks on the train, and the brake should then be fully applied, and the time during which the air continues to rush in through the application valve should be noted. This will give the driver a good idea as to whether the vacuum hose pipes are coupled throughout the train, as on a long train of about 140 axles the rush of air should be heard for about half a minute. It must be remembered that while the application valve handle is in the full 'on' position, the small ejector is isolated from the train pipe, and is not drawing air through the application valve.

When the air stops flowing, the brake has been fully applied throughout the train. The brake should then be released again, assisted by the large ejector if time is limited. Care must always be taken when using the large ejector to avoid allowing the vacuum to rise to an amount higher than the small ejector can maintain, as if this should happen, a higher degree of vacuum will exist above the brake pistons than can be maintained below them, and the brakes will remain slightly applied.

It will be found in most cases that it takes a considerably longer time to create vacuum when the engine is originally coupled to the train than it does after the brake has been fully applied. The reason for this is that the release valves of all the vehicles have usually been opened, and the whole brake system, including the vacuum chambers, is full of air. After vacuum has once been created and the brake has been fully applied, only the air in the train pipe and below the brake pistons has to be withdrawn.

The brakes on a train should always be handled as gently as possible. It is not often necessary to make a full application provided a proper look out is maintained by both the driver and the fireman. In general, the method of working the brakes on a train is similar to that used on a motor car. The brakes should be applied in good time, and as the train comes to a stop they should be coming off steadily to avoid jerking. Similarly when approaching a curve the train should be checked and where possible allowed to accelerate slightly after entering the curve. The main difference between the brakes on a train and those on a motor car is that a train consists of a large number of vehicles instead of a single one, and that the brakes cannot be applied or released at absolutely the same time on every vehicle. The brakes come on sooner at the front of a train than they do at the back, and also release sooner at the front, so that unless the brakes are handled with care, bunching and jerking are bound to occur. It has been found on tests that with a train of 140 axles it takes approximately 35 seconds after the application valve handle on

the engine has been moved to the full 'on' position before the brakes on the van have been fully applied.

In addition, the adjustment of the brake gear on the various vehicles composing the train is never exactly the same, so that the brakes on some vehicles will take effect more quickly than those on others. It is therefore always important to 'set the brakes' by reducing the train pipe vacuum by 2 or 3 inches for a little while before a stop is required, thus taking up the slack in the brake gear on all the vehicles. A harder brake application can then be made without the risk of severe bunching and jerking. Care must also be taken not to release the brakes too rapidly as the train is stopping, since a severe jerk is often caused by the brakes at the front of the train being practically off while those near the back are still on. The large ejector should not normally be used to release the brakes as the train is coming to a stop, as on a long train this can easily break a buffer towards the rear if the brakes had previously been applied fairly hard.

The vacuum brake can be applied from the guard's van, where a valve is provided for the purpose. This valve was originally designed as an automatic valve which would admit air to the train pipe if a heavy brake application were made by the driver, but as the automatic feature was found not to work on long trains, it was altered by inserting a spring above the valve. The valve as now fitted to guards' vans and many private saloons is much easier to operate, as a steady brake application can be made. No means are provided for releasing the brakes from the guard's van.

Main line saloons and dining cars are fitted with a 'vacuum stop alarm'. This consists of a small valve on a branch from the train pipe. The valve is opened by a wire attached to a lever inside a glass case in the corridor of the saloon, and will give a comparatively light brake application when it is opened. Drivers of passenger trains must be on the alert for any slight application of the brakes from a vacuum stop alarm, as these are for use in emergencies. It is sometimes found that after the stop alarm valve has been opened, it will not return to its seat, and it is then necessary to locate the valve and put it back by hand. The valve can easily be found by noting the position of the glass caste of the alarm lever, and then removing one or two of the outside dado boards of the saloon immediately below the case. The valve will be found inside the hollow side of the saloon body.

Leakage of air in the vacuum brake system may be either external or internal leakage. External leakage occurs when air from outside the system leaks in. This always goes on to some extent, and if serious will affect the brakes on the whole train. Provided the small ejector on the locomotive can overcome the external leakage and still maintain the minimum amount of vacuum laid down in *Clause 19(5), Section 1 of the General Appendix (Part 1)*, the brakes

will work satisfactorily, except when the external leakage is into the vacuum chamber or its connections.

Internal leakage occurs when air from the train pipe, which is being used to apply the brakes, leaks past ball valves, piston rod caps or rolling rings. The effect of this is serious, as the brakes worked by the cylinders concerned will leak off more or less rapidly, and when descending long gradients the train may get out of control. Fairly frequent recreation of vacuum reduces the effect of internal leakage, but does not stop the leaks.

External leakage can nearly always be heard when vacuum is created, and the defect can usually be remedied fairly easily. Internal leakage can be detected by creating the normal amount of vacuum and then applying the brakes fully. If the pistons drop in less than about ten minutes, and thus release the brakes, the internal leakage is too serious to neglect, and the vehicle or vehicles concerned should, if at all possible, be attended to at once by the carriage and wagon staff.

It sometimes happens that the vacuum in the train pipe, the vacuum chambers and in the upper parts of the cylinders rises to a degree, higher than can be maintained by the small ejector. This may be caused by careless use of the large ejector as mentioned earlier, and can also occur when locomotives are changed, if the small ejector on the incoming engine is maintaining a higher vacuum than that on the outgoing engine. The same thing can happen when vehicles are picked up by a tram. The brakes will drag for a considerable time, in fact until internal leakage releases them, unless the vacuum above and below each piston is equalized. This is done by pulling the release wires attached to the release valves, thus opening communication between the tops and the bottoms of the cylinders. It is the duty of the fireman and guard to do this where no carriage and wagon staff are stationed. See *Sub-paragraph 19(17), Section 1 of the General Appendix (Part 1).*

When the brake gear on a vehicle is badly adjusted so that the piston has to rise a long way in the vacuum cylinder before the brake blocks are pressed against the wheels, the vehicle is said to have a 'long brake'. Such a brake takes longer to apply than when the gear is correctly adjusted, and in addition is never as powerful as it should be, since the low pressure air above the piston and in the vacuum chamber is compressed much more than is necessary. The result of this is that there is less difference of pressure acting on the piston, as mentioned earlier in this Section.

Due to defects in vacuum cylinders, sticking pistons are frequently experienced. When this happens, the hose pipe at one end of the vehicle concerned should be uncoupled, the release wire pulled and the vacuum

recreated. If the piston does not come down, an attempt should be made to force it down with a bar. If this does not work, a through pipe must be made, by knocking out the pin connecting the piston rod to the brake shaft lever, uncoupling the branch hose pipe from the nipple on the train pipe and plugging the nipple with a wooden plug. Where a hand brake is fitted, removal of the piston rod pin will be made easier if the hand brake is first applied as hard as possible. In this connection, see *Clause 19(23) Section I of the General Appendix (Part 1).*

Heating of brake blocks through continuous use of the brakes has no noticeable effect on the brake power. The loss of brake power often experienced after a long application is the result of loss of chamber vacuum through internal leakage and external leakage into vacuum chambers and their connections, hence the necessity for recreating vacuum.

STEAM BRAKE

Most locomotives on the S.A.R. are fitted with a steam brake. This consists essentially of a cylinder mounted in a convenient position on the engine frame and fitted with a piston and a piston rod, which is connected to a lever on the steam brake shaft. A pull rod from a second lever on this shaft is coupled to the brake rigging which applies cast iron brake blocks to some or all of the coupled wheels. The bogie and bissel wheels, where provided, are not fitted with brakes.

Fig 89 shows a typical steam brake arrangement.

The cylinder may be mounted either vertically or horizontally, depending upon the space available on the engine frame, but its action is the same in both cases. Steam from the boiler forces the piston either into or out of the cylinder, thus applying the brakes, and when this steam is released to exhaust the brakes are pulled off and held off by a spring known as the brake release spring.

While a few of the older classes of locomotive have an independent valve controlling the supply of steam to the steam brake cylinder, most engines are fitted with a valve which can be worked either by hand or automatically in conjunction with the vacuum brake. This valve is mounted on the left hand side of the ejector, and is supplied with steam direct from the ejector. **Fig 90** shows the arrangement.

The valve is provided with a vacuum cylinder and a piston, which is coupled by means of an external lever to the steam valve. The inner side of the vacuum piston is directly connected to the train pipe chamber in the ejector body by means of two passages, a large one fitted with a ball valve, and a very

small one which remains open. The outer side of the vacuum piston is always open to the atmosphere.

When a vacuum is created in the train pipe, it is also created on the. inner side of the piston, and the air pressure on the outer side forces the piston into the cylinder, and by means of the external lever holds the steam valve firmly on its seat. When air is admitted to the train pipe to apply the brakes on the train, the ball valve closes the larger passage to the vacuum cylinder, and air enters through the small passage only. The vacuum on the inner side of the piston is thus destroyed slowly, until the steam pressure on the face of the steam valve overcomes the reduced holding power of the vacuum piston. The steam valve then opens, admitting steam to the steam brake cylinder. The steam valve also acts as an exhaust valve, and when it is open to steam the exhaust passage is closed. A collar is formed on the steam valve, and as soon as the steam starts to flow it acts on the collar as well as on the face of the valve, and thus balances it, so that very little force is needed to close it, When vacuum is again created in the train pipe, the air acting on the inner side of the vacuum piston is withdrawn past the ball valve, and the piston moves into the cylinder. The external lever pulls the steam valve on to its seat, and at the same time opens the exhaust passage, thus releasing the steam brake.

The external lever projects below the valve, and forms a handle for working the steam brake by hand. A trigger attached to the valve casting fits over a peg on the external lever, so that the steam valve can be held closed when the vacuum brake is operated.

The steam brake is provided mainly for emergencies, and need not normally be used when working a train. As it must, however, be available for use all the time, it is essential that it be tested at least once every trip. The steam brake is sometimes severe in its action, and may cause the coupled wheels to skid and develop serious flats, so that it is always desirable to test it when moving slowly, and thus reduce the possibility of damage being done. If the coupled wheels are found to skid when the steam brake is used, the brake gear must immediately be booked for adjustment. See *Clause 62, Section IX of the General Appendix (Part 1).*

Many Garratt locomotives are fitted with vacuum brakes on one unit (usually the leading one) and steam brakes on the other unit. While the steam brake is primarily intended as an emergency brake, the vacuum brake is provided for regular use whenever the train brakes are applied. The most modern tender locomotives are fitted with vacuum brakes on the engine as well as on the tender, and on these locomotives no steam brake is provided. Here, also, the engine vacuum brake is intended for use every time the train brakes are applied, thus providing increased brake power and increased safety, particularly when handling heavily loaded trains.

The isolation valve can be seen in **Fig 86A** and **Fig 88A**, and the are controlled by an auxiliary train pipe. The normal train pipe runs the length of engine and tender as usual. The auxiliary train pipe is joined to the main train pipe at the driver's brake application valve assembly by means of the driver's isolation valve.

The isolation valve can be seen in **Fig 86A** and **Fig 88A**, and the vacuum piping and vacuum brake component layout of a modern locomotive in **Fig 90A**.

In the 'running' or 'off' position this valve merely joins the auxiliary to the main train pipe. In the 'on' position the auxiliary train pipe is isolated from the train pipe and opened to atmosphere. The engine and tender brakes are therefore fully applied. This valve is of great assistance to the driver as it enables him to blow off the train brakes completely while holding it with the locomotive brakes. When ready to leave he merely moves his isolation valve to the 'running' or 'off' position which releases the brakes on engine and tender and he can then start without having the train brakes dragging. It thus enables the driver to comply with the provisions of *Paragraph 13, Clause 19, Section I, of the General Appendix (Part 1).*

Another advantage is that the driver can use the valve to prohibit any movement of a train while taking water or oiling and greasing without having to destroy the train vacuum.

Fig 90A also shows the delay action valves placed between the auxiliary train pipe and the vacuum brake cylinders. These valves are now provided for the reason that while full brake power on the locomotive must be available to assist in controlling and stopping heavy trains and when working light engines, it is not necessary to apply engine and tender brakes when only relatively light brake applications are made on the train during normal working.

Further, as stated earlier, it takes time for the air to pass down the train pipe to the rear of the train and the brakes are applied on the locomotive and front portion of the train first and cause a certain amount of 'bunching'. The delay action. valves do not allow air to pass to the brake cylinders until 8-10 in. of train pipe vacuum have been destroyed. Hence, with light brake applications, the locomotive brakes are not operated thus saving the 'bunching' action due to braking of the locomotive and saving unnecessary brake block and tyre wear and other wear on engine parts. The control of the train is also smoother.

For heavier or emergency braking, when more than 8-10 in. of train pipe vacuum is destroyed, air is allowed to pass to the brake cylinders on the locomotive and the full brake power is available for controlling the train.

When working 'light engine' the driver has to reduce the main train pipe vacuum sufficiently to operate the delay action valves and hence the brakes. Once used to this, there is no difficulty in controlling the engine.

It is of the greatest importance for enginemen and shed staff to remember this, and in no circumstances to interfere with the working of engine vacuum brakes. These must be working every time the train brakes are applied. On engines without steam brakes it is obvious that no proper control will be available when the locomotive is running light unless the engine vacuum brake as well as the tender brake are in good order. The vacuum brakes on locomotives and on tenders must be kept in proper adjustment, and enginemen must ensure that any defects are fully booked. While no driver would be foolish enough to take out an engine with the tender brake not working, it must be clearly understood that is just as foolish to work a locomotive without a proper engine brake.

Cases have occurred where engine or tender brakes have been kept out of use on the road by holding the release valve open with a piece of wood or a small stone. This is a most dangerous practice, and cannot be permitted.

General instructions for working the vacuum brake are given in *Clause 19, Section I of the General Appendix (Part 1).* Further instructions are given in *Clauses 43(3) & 43(8), Section II of the General Appendix (Part 1).* The following Train Working Regulations also apply: *Nos 169, 170, 176(4), 184(3), 193(2)(b), 194, 198(3) & 198(4).*

The following instructions and regulations concern the use of the vacuum brake during shunting operations: *Clause 1(1), Section IX of the General Appendix (Part 1), Train Working Regulations Nos 69, 134(2) & 142(1).*

The following instructions refer to the use of the steam brake: *Clause 19(12), Section I & Clause 43(18) Section II of the General Appendix (Part 1).*

All these instructions and regulations should be carefully studied, and must not be forgotten.

Further remarks concerning the use of brakes will be found in **Section 12** of this Handbook.

SECTION 8

TENDERS & ARTICULATED LOCOMOTIVES

Purpose of tenders. Wheel arrangement. Frame. Bogie centres. Bogies, plate frame & bar frame. Types of axle-box. 'Isothermos' axle-box. Brakes. Tank & coal bunker. Securing of fire irons. Details of water tank. Through water pipe. Intermediate draw gear & cushion buffers. Pipe connections between tender & engine. Classification of tenders.
Definition & purpose of articulated locomotives. Types in use on S.A.R. Description of Mallet locomotive. Description of Garratt locomotive. Cylinder drain code & sanding gears. Flexible & expansion joints. Lubrication & maintenance of pivots. Double heading. Modified Fairlie locomotive. Union locomotive.

TENDERS

Most locomotives are provided with tenders for carrying the water and fuel necessary to roan for reasonable distances without having to take on fresh supplies. The tender is a separate vehicle which is coupled to the locomotive proper, and, as the two are seldom separated except for repairs, the locomotive and its tender are normally regarded as one machine.

With the exception of a few obsolete types which are rapidly disappearing, all the tenders on the S.A. Railways are carried on two bogies. These bogies are nearly all of the four-wheeled type, but some six wheeled bogies are in use. The tender has a strong steel underframe, provided with two pivots or top bogie centres, which fit into sockets or bottom bogie centres bolted to the bogies. These are now normally of the oil bath type, and clamps are fitted to prevent accidental separation of the top and the bottom bogie centres.

The older types of tender bogie have frames made of two steel plates, rigidly secured together by means of stretchers and crossbars. The bottom bogie centre is bolted firmly to the centre crossbar, and no side play or side control springs are provided. Gaps are cut in the frame to take the axle-boxes, and these gaps are provided with horn blocks and horn shoes. The axle-boxes are always fitted outside the wheels. A single semi-elliptical laminated spring is used on each side, in a similar manner to the engine leading bogie. The spring buckle is secured to the bogie frame by means of a large pin, while the ends of the spring are attached to the compensating beam (sometimes called the equalizing bar) by spring hangers. The compensating beam rests at its ends in slots formed in the tops of the axle-boxes. The axle-boxes of plate frame tender bogies are fitted with plain bearings lined with white metal, and are lubricated by means of wool waste soaked in oil which is packed into the axle-box below the axle journal. If the axle-boxes are properly packed, and

provided they receive regular attention in the running shed, little trouble is experienced with bearings of this type. It is important for the driver to see that the horn fares of all bogie axle-boxes are lubricated.

The more modern tenders are fitted with bogies having bar frames. These consist of two heavy steel bars, one on each side, connected by stretchers and crossbars. The axle-box guides are cast steel pedestals bolted to the frame bars at the top, and fitted with a stay bar underneath which connects all four pedestals on each side. The bottom bogie centre is bolted securely to the centre cross bar of the bogie, no side play being provided for. The spring arrangement is similar to that used on the plate frame bogie, except that the top of the spring buckle rests in a saddle formed on an extension of the centre crossbar and no pin is used. Compensating beams and spring hangers are fitted, as on the plate frame bogie. **Fig 91** shows the arrangement of a bar frame tender bogie.

Three types of axle-box are used on bar frame bogies. These are the ordinary plain bearing type, as on the plate frame bogie, the roller bearing type, and the 'Isothermos' axle-box. This axle-box is fitted with plain white-metalled bearings, but, instead of being packed with waste soaked in oil, it is lubricated by oil which is splashed against the axle journal by means of an oil 'slinger', which is made something like a fan, and is attached to the end of the axle. **Fig 92** shows the arrangement of an 'Isothermos' axle-box.

Tenders are always fitted with both vacuum and hand brakes. It is usual to have two vacuum cylinders mounted on the tender underframe, but normally only one vacuum chamber is fitted, which in many cases is placed on the top of the tank just behind the coal bunker. As mentioned in **Section 7**, the cylinders are provided with double branch ball valves, but not usually with release valves. The vacuum chamber is connected directly to the ejector, where vacuum brakes are not fitted on the locomotive itself, and the release valve for the tender brakes is immediately below the ejector. A diagram of the tender vacuum brake piping is shown in **Fig 93**.

The water tank and the coal bunker are made in one unit, which is mounted on top of the underframe and held down by bolts. The water capacity of modern tenders is usually about 6000 gallons, while the coal bunker will hold about 15 tons. Where a mechanical stoker is used, the stoker engine is fitted in a compartment at the left or right hand front corner of the tender tank, as mentioned in **Section 4**.

Brackets for carrying the fire irons are fitted to the left hand side of the tender, near the top, and it is most important to see that at all times the fire irons are placed on the brackets in such a way that they will not fall off. The attention of all concerned is drawn to *Train Working Regulation No 163.*

Before leaving the running shed, an adequate supply of coal and water must be available in the tender - see *Train Working Regulation No 161(1).* In order to prevent lumps of coal from getting into the tender tank, coal must not be allowed to accumulate on the top of the tank behind the bunker, and after water has been taken the tank lid must be closed. It is also most important to see that the trunk or hosepipe used for filling the tender tank is properly secured after use, see *Clause 41A, Section IX of the General Appendix (Part 1).*

The attention of all concerned is also directed to *Clauses 39 & 62, Section IX of the General Appendix (Part 1).*

The water supply for the injectors on the locomotive is taken from two valves or cocks on the underside of the tender tank, near the front. On the more modern tenders a strainer is provided in a separate casing outside the tank, while on the older tenders the strainer is inside the tank. Inside the tank a number of baffle plates is fitted to prevent the water surging unduly when the tank is not full. These plates also serve to stiffen the sides of the tank.

All tenders have a connection at the rear end for draining the tank and also for use when a travelling water tank is coupled behind the tender. The connection is fitted with a valve or a cock. On some tenders a pipe runs from the rear along the underframe and is connected through a suitable valve to the injector feed pipe, so that water from a travelling water tank may be fed direct to one injector, usually the left hand one, without having to draw on the tender tank. This has the advantage of allowing all the water in the travelling tank to be used, which is not possible if this water has to flow into the tender tank before reaching the injector. The reason for this is that the bottom of the tender tank is higher above rail level than the bottom of any normal travelling tank.

The rear end of the tender is fitted with a buffer and drawgear similar to that used on trucks. The tender is connected to the engine by means of a strong steel intermediate drawbar, which is secured to a drag box at the leading end of the tender by means of a pin and a split cotter. A drag box is also fitted at the rear end of the locomotive itself, and a pin passes through this drag box and through an elongated hole in the drawbar. On most tenders no springs are provided for the drawbar. Some of the older classes of tender are fitted with two cushion buffers, but the majority of tenders have only one cushion buffer between the tender and the engine. This may be fitted either below or above the drawbar, and it presses against a pad on the back buffer beam of the locomotive. It is essential that the cushion buffer be well lubricated to allow it to slide freely over the pad on the buffer beam. A strong spring is fitted inside the tender drag box, and this presses the cushion buffer firmly against the back buffer beam of the engine, thus holding the drawbar tight.

When coupling the tender to the engine it is necessary to push the tender hard against the engine so as to compress the cushion buffer spring sufficiently to allow the drawbar pin on the engine to pass through the elongated hole in the drawbar. The hole at the engine end of the drawbar is elongated so as to allow for further compression of the cushion buffer spring when the tender is bumped while coupling up to a train or while shunting. Safety chains are fitted between the tender and the engine in case the intermediate drawbar should break. **Fig 94** shows a modern design of drawgear.

The connections between the engine and the tender for supplying water to the injectors, and for the vacuum brake and steam heating of passenger trains are all made by means of flexible hoses, of which there are generally five - two for the injectors, one for the vacuum brake train pipe, one for the vacuum brake chamber pipe (which is a small one) and one for steam heating. The steam heating hoses are removed in the summer.

Tenders are classified by two letters with or without numbers. The first letter indicates the classes of engine to which the tender can be coupled, and the second indicates the water capacity. Numbers are used to indicate minor differences which the letters would not show. The classification is marked below the tender running number on the number plate fixed to the rear end of the tank.

ARTICULATED LOCOMOTIVES

An articulated or jointed locomotive is one in which there are two or more independent groups of wheels at least one of which can turn relatively to the boiler, in a manner similar to a bogie or to a bissel. While many different designs have been developed, only four types are now in use on the S.A.R.

The purpose of any articulated locomotive is to provide an engine of considerable power but with comparatively low axle loading. As mentioned in **Section 5**, the coupling together of several pairs of wheels overcomes the difficulty of restricted axle loads, but the curvature of the track sets a definite limit to the length of the rigid wheel base, and therefore to the number of pairs of wheels of any given size which can be coupled together. If the permissible axle load is fairly low on account of light track or weak bridges, the only way to provide sufficient coupled wheels to transmit the required power is to separate these wheels into two or more groups, each group being usually driven by an independent pair of cylinders. Such a locomotive can be made sufficiently flexible to run on severely curved track without trouble. Each group of wheels is usually referred to as a ‘unit’.

The four types of articulated locomotives used on the S.A.R. are the Mallet, the Garratt, the Modified Fairlie and the Union. The Garratt has become the standard design of articulated locomotive on the S.A.R., and the other three types are disappearing fairly rapidly, so they will be dealt with only briefly.

The Mallet locomotive has two groups of coupled wheels, the rear group being mounted on the main frame of the engine, and being therefore rigid. The front group has a separate frame of its own, and this is coupled to the rear group by means of a type of hinged joint, so that it can swing within limits to either side, in a manner similar to that of a bissel. The firebox of the boiler is carried on the main frame, and the smokebox rests on a flat slide on the front frame. A separate tender is coupled to the locomotive in the usual manner, while the buffer and drawgear at the front end of the engine are mounted on the frame of the front unit.

The engine has four cylinders, and is worked on the compound expansion principle. The two high pressure cylinders are fitted on the main frame and drive the rear group of coupled wheels, and the exhaust steam from these cylinders is taken through a pipe to the low pressure cylinders mounted on the front unit, these cylinders driving the front group of coupled wheels. The steam is thus used twice before being exhausted through the blast pipe to the atmosphere. The Mallet is the only type of engine on the S.A.R. using compound expansion.

The steam pipe from the high pressure cylinders to the low pressure cylinders is fitted with a ball and socket joint immediately above the articulating joint between the two units, and also with a sliding expansion joint. The exhaust steam from the low pressure cylinders is led through passages in the saddle between the cylinders, from which it is taken through a pipe fitted with two ball and socket joints and a sliding joint to the blast pipe in the smokebox.

The high pressure cylinders are fitted with inside admission piston valves, while the low pressure cylinders are fitted with slide valves. Each unit has its own set of Walschaerts valve gear, so arranged that while the die blocks of the low pressure unit are in the lower portion of the expansion links in fore-gear, the die blocks of the high pressure unit are in the upper portion of the expansion links in fore-gear. This has the effect of balancing the weight of the motion coupled to the reversing gear, and makes the notching up and reversing comparatively easy. It should be noted that the same reversing gear works both sets of valve motion, so that as the motion on one unit is notched up, that on the other is also notched up to the same extent.

Fig 95 shows a Mallet compound locomotive.

The Garratt locomotive, of which a considerable number of various classes, both standard gauge and narrow gauge, is in use, is entirely different from the Mallet. Two units, each driven by a pair of cylinders at its outer end, are provided, and these are connected together by a steel frame known as the cradle, which carries the boiler. A water tank is carried on brackets attached to the frame of the front unit, while a combined coal bunker and water tank is carried on similar brackets on the frame of the back unit. The locomotive is thus entirely self-contained, and no tender is used. The two water tanks are connected by an equalizing pipe fitted with a valve for closing off one tank.

The units are coupled to the cradle by means of pivots similar to bogie centres, so that each unit can rotate as much as is necessary on curved track.

Fig 96 shows the general arrangement of a typical Garratt.

The four cylinders all take high pressure superheated steam direct from the superheater header, the pipe on the left hand side supplying the front unit and that on the right hand side supplying the back unit. Each unit has its own set of Walschaerts valve motion, and is completely independent of the other unit except that the regulator controls the steam supply to both units simultaneously, and one set of reversing gear controls both sets of valve motion. The steam pipe to each pair of cylinders is fitted with the necessary ball and socket joints and expansion joints to allow of movement between the unit and the cradle carrying the boiler. The same is done with the exhaust pipes, both of which are connected to a single blast pipe in the smokebox. Only one steam pipe and one exhaust pipe are used for each unit, the pipes being divided into two branches between the cylinders. Two hydrostatic lubricators are fitted in the cab, one for each unit.

The cylinder drain cocks and the sanding gear on each unit are worked by small steam cylinders,, controlled from valves in the cab. These valves are the same as those used for the grate shaking donkey, and the valves and the operating cylinders are lubricated through small branch pipes in exactly the same manner as the grate shaking donkey - see **Section 4**.

The buffer and its drawgear at each end are carried on the unit frame, and an electric headlamp is mounted on the tank in front and on the coal bunker at the back. The locomotive will run equally well in either direction.

The design of the ball and socket joints and of. the expansion joints varies somewhat in the different classes, but the general principles are the same. **Fig 97** and **Fig 98** show a typical joint of each type.

When booking repairs to a Garratt or any other type of articulated locomotive, it is essential to state which unit is being referred to, as the names of the

parts are in general the same as on an ordinary rigid frame locomotive, and similar parts are used on both units.

A Garratt locomotive has four exhaust beats per revolution for each unit, so that often eight beats can be heard. There is always a tendency for the two units to get into step with each other, giving only four beats, but sometimes they do not remain in step for long. As each unit is in effect an independent locomotive (except for the boiler) any breakdown which will put one cylinder out of action is not as serious as it is on an ordinary locomotive, as there are still three cylinders left, only a quarter of the tractive force instead of a half being lost. It is therefore very often possible to carry on without having to reduce the load.

The pivots connecting the cradle to the unit frames must at all times be well lubricated, and any noticeable wear must be taken up as early as possible. It must be remembered that these pivots not only carry the weight of the boiler and the cradle, but have to transmit the tractive force of the units as well. If wear develops, the pivots will bump badly while the locomotive is steaming. To avoid damage to the pivots and other parts of the locomotive, a Garratt should normally be the leading engine when double-heading is necessary. If it is essential to use two Garratts on a train, it is better where possible to place one of them in the middle or at the rear of the train, rather than to marshal both at the front. The attention of all concerned is drawn to *Clause 43(2), Section II of the General Appendix (Part 1).*

The Modified Fairlie locomotive, of which only a few are now in use, is similar to the Garratt, the main difference being that the front water tank and the combined coal bunker and water tank at the rear are carried on extensions of the boiler cradle and not on the unit frames. The units act as bogies, and have jointed steam and exhaust pipes as in the Garratt.

The Union type of articulated locomotive is a cross between the Garratt and the Modified Fairlie designs. The front unit carries a water tank on the unit frame, as in the Garratt, while the boiler cradle is extended over the back unit to carry the coal bunker. No water tank is provided at the back, but a tank is fitted to the cradle underneath the boiler barrel. Only twelve engines of this type, in two classes (**GH** and **U**) have ever been built, and it is unlikely that they will be repeated.

The S.A.R. have been prominent for many years in the use of articulated locomotives, and many different designs have been tried. At present the Garratt holds first place, but as articulated loco motives are always likely to be of great use in South Africa, other types may be introduced in the future.

SECTION 9

MANAGEMENT OF BOILERS IN THE SHED & ON THE ROAD
Lighting up. Raising steam. Use of compressed air. Examination of boiler by driver & fireman. Testing of water gauges. Examination of firebox. Testing of injectors. Testing of ashpan coolers, firebars & ashpan slides. Examination of outside of boiler. Safety valve seals. Examination of smokebox. Preparing the fire. Firing on the road. Holes & banks in the fire. Thick smoke. Use of blower. Keeping the fire clean. Use of ashpan coolers & ashpan slides. Levelling piles of ashes between the rails. Use of injectors. Starting & shutting off injectors. Correct water level in boiler. Priming and its results. Causes & prevention of priming. Use of boiler compounds. Use of blowdown cocks. Cleaning or dropping fires on the ash pit. Banking of fires. Moving without fires. Procedure where no ash pit is provided. Blowing steam out of the boiler. Damage caused by cold air. Causes of bad steaming. Locating & booking of defects. Dealing with leaking tubes. Renewing gauge glasses. Clearing choked steam & water passages. Locating & dealing with injector & clack box defects. Working of mechanical stoker.

MANAGEMENT OF BOILERS

When lighting up a boiler, certain important matters must be attended to if serious damage is to be avoided. Apart from these, insufficient attention to various other points may cause delays on the road or in leaving the running shed.

The procedure when lighting up a boiler is as follows:

1. See that the boiler has about one third to a half glass of water, and check the level showing in both gauge glasses by opening and shutting the test cocks. The steam and water cocks on both water gauges must be wide open, with the handles in the vertical position.
2. Make sure that the regulator is properly closed and that the cylinder cocks are open.
3. See that all washout and arch tube plugs have been properly replaced and are not leaking. If there is the slightest doubt about this, the washout man or the boilermaker should be called immediately.
4. See that the grate is thoroughly clean, and that the bars are in good order and are properly closed. See that the ashpan is clean and that the slides are closed. While examining the ashpan it is important to see that the grate operating rods are properly coupled up.
5. Open the smokebox door, and see that the smokebox is clean, that all the spark arresting gear is in position and properly secured, and that the perforated plates or wiremesh plates are thoroughly clean. Then close the door tightly.

6. Spread a *thin* layer of coal from the tender over the whole grate, and then put in chopped up wood or burning coal from the lighting up furnace. This should be placed against the tube plate, under the brick arch. If wood is used, some dirty waste soaked in paraffin will be needed to start the fire, and in any case a piece of such waste when burning gives quite a useful light inside the firebox.
7. Once the fire has started to burn under the brick arch, a little fresh coal should be added and allowed to burn up. If the fire does not spread by itself towards the back of the grate, it should be carefully pulled back until the whole grate is covered with burning coal. Coal should be added a little at a time until the fire is burning well. Constant attention is necessary, and at all times the water gauges must be watched. As the boiler heats up, the level of the water in the gauge glasses will rise somewhat, due to expansion of the water.

The attention of all concerned is drawn to *Clause 42(3), Section IX of the General Appendix (Part 1).*

Once the fire has been properly established, the raising of steam in a boiler must be gradual, and *at least* one and a half hours must be taken to raise the pressure to 50 lb per square inch, after which it can be raised gradually to full pressure. Wherever possible, engines should be lit up at least four hours before they are required to leave the running shed.

By suitably adjusting the amount of partially burnt coal placed on the grate for lighting up, the times mentioned above can normally be adhered to in practice, but if difficulty is experienced in raising steam within these limits, and a locomotive is urgently required for traffic purposes, compressed air may be used for accelerating the rate of steam generation. Great care must be exercised when using compressed air, and officers in charge of sheds must maintain strict supervision of this practice, as damage can be done to boilers if compressed air is used indiscriminately.

The only method of using compressed air which is permitted is to admit the air through the fitting attached to the end of the blower pipe outside the smokebox. The hole in this fitting is limited to a maximum of half an inch in diameter. The blower valve on the turret must remain closed while compressed air is being used. The use of ring blowers in the chimney is not allowed. When no compressed air is available, it is often possible to use steam from another engine.

When the boiler pressure has reached 50 lb per square inch, the compressed air must be shut off, and if necessary, the steam blower may then be used for increasing pressure. It must be remembered, however, that as the pressure rises, the steam blower will create more and more draught, so that it will

need to be closed slightly from time to time, if excessively rapid rise of pressure is to be avoided.

When the driver and the fireman come on duty, their first job on arrival at the engine is to examine the boiler. The steam pressure should be noted, and the pressure gauge cock should be examined to see that it is fully open. The water gauges should then be examined and tested to ensure that they both show the true water level in the boiler. The proper method of testing the water gauges is as follows:

1. Ensure that the gauge glass protectors are properly in position.
2. Close the steam and water cocks, and open the drain cock.
3. Open the water cock, with the drain wide open. If there is a strong blow out of the drain pipe, the water passage to the boiler is clear. The water cock should then be closed.
4. Open the steam cock, and close again, thus testing the steam passage to the boiler.
5. With the drain still open wide, open both steam and water cocks, and then close the drain slowly. The water will then rise to the correct level. Both steam and water cocks must then be kept *fully open.*

If the water should not rise rapidly, and remain moving slightly up and down in the glass, there is a defect either in the passages or in the glass, and a fitter should be called immediately so as to avoid delay in leaving the shed. The way to deal with defects which develop on the road will be described later, but at all times the test cocks should be frequently used to check the water gauges.

After testing both water gauges, the firehole door should be opened and the blower put on very slightly. The state of the fire should be checked, and the interior of the firebox should be examined. The main points to look at are:

1. Fusible plugs, to see that they are not leaking.
2. Brick arch and deflector plate.
3. Tube plate and tube ends.
4. Sides and crown, to see that there are no discoloured patches, bulges, or stays leaking.

Any defects noted should immediately be reported, otherwise the driver may be held responsible.

Both injectors and the clack valve stop cocks should then be tested, and the ashpan cooler cocks should be opened. The grate should then be given a light shake, to ensure that the firebars are working freely, after which the injectors and the coolers may be shut off, and the firehole door closed. The ashpan slides should then be opened and dosed, and the ashpan should be given a final check over to make certain that the slides are properly dosed, that the coolers work correctly and that everything is in order.

The seals on many safety valves are easily visible, and these should be looked at to see that they are intact. The outside of the boiler should be looked over to see if the dome and manhole joints are tight, that no washout or arch tube plugs are blowing, and that there are no blows under the lagging.

The smokebox next requires attention. With the blower still very slightly on, the smokebox door should be opened, and any ashes lodged between the door and the liner and deflector plates should be removed by tapping these plates lightly with a hammer shaft. The things to look for inside the smokebox are:

1. That the drain plug is in position.
2. That the washout plugs in the front tube plate are not blowing, and that the tubes are clear, as far as can be seen.
3. That the diaphragm plate, table plate and breaker plate are properly secured and have no holes or gaps in them.
4. That the perforated plates or wire meshed plates are properly secured, fit together correctly and have no excessively large holes in them. They must also be clean, and if necessary a wire brush must be used to clean them. Striking perforated plates or wire mesh plates with a hammer is not allowed and does not help. The conical spark arrestor fitted between the blast pipe cap and the table plate on certain classes of engine must not be overlooked.
5. That the blast pipe, blast pipe cap, petticoat and chimney are in order and properly secured, as far as these parts can be seen, and that the blower and the vacuum ejector exhaust pipes are coupled to the blast pipe cap, and that the flange joints are not blown out.
6. That the main steam pipes are intact and that the joints show no signs of blowing.
7. That the crossbar inside the door opening is resting properly in its brackets.

Any defects observed must be reported immediately.

Before closing the smokebox door, the rim of the door as well as the angle iron ring on the smokebox front, against which the door fits, must both be wiped clean, and a thin film of oil must be smeared on the rim of the door. The door should then be closed firmly, making sure that the dart is properly engaged with the crossbar. The door must finally be tightened up, after which it should be checked to see that it is properly closed all round.

The last thing to be done is to brush any ashes or char off the front platform. The attention of enginemen and shed staff is drawn to the instructions contained in *Clauses 38(7), 42(3) & 42(5), Section IX of the General Appendix (Part 1).*

After the boiler has been examined, the fireman should prepare the fire so that all will be in readiness by the time the engine is coupled to the train,

bearing in mind the work which the engine will have to do at the start. Care must also be taken to see that the safety valves do not blow off while the engine is near the station.

When building up the fire, the blower should be opened slightly, and coal placed mainly in the back corners and along the sides of the firebox. The fresh coal put in must be allowed to burn through properly before more coal is added at that point, otherwise clinkers may easily develop. It is also most important that the fire be thoroughly clean before the engine leaves the shed.

As the coals from different collieries, and even from different parts of the same colliery, vary considerably in composition, rate of burning and other properties, and as locomotives even of the same class show surprising differences in the way they burn the fire, no absolutely definite rules can be laid down as to how to fire on the road. Certain general principles, however, can be applied in almost all cases, provided this is done with reasonable intelligence. A careful study of the job of firing is well worth the trouble, as it will save the fireman (and others) a great deal of unnecessary work.

The most important condition to aim at is to keep the steam pressure as constant as possible close to the blowing-off point, without allowing the safety valves to open. This maintains the firebox at a reasonably even temperature, thus preventing a great deal of trouble with leaking tubes, broken stays, cracked plates and leaking seams.

To maintain this constant temperature, the fire should be kept bright and as thin as conditions will permit. Firing should be done a little at a time and no more often than is necessary, depending upon the work the engine is called upon to do. It is always a good practice to close the firehole door between shovelfuls, as this greatly reduces the amount of cold air drawn into the firebox, and also gives the coal just fired a chance to ignite properly. It must be remembered that the more air that is drawn through the firehole, the less is drawn through the grate.

Holes in the fire cause great trouble by allowing large volumes of air to be drawn through, thus starving the rest of the fire. Holes can easily be seen by an experienced fireman and they should be immediately repaired by moving burning coal over them with the pricker. Similarly banks or thick places restrict the draught, and reduce the rate of burning, and they should be spread out if possible, or allowed to burn through before any more coal is fired in that area.

Most locomotives burn the fire more rapidly in the back corners, along the sides and next to the tube plate than they do in the middle of the grate, so that firing should be concentrated mainly in these areas. It will be found that

as a rule sufficient coal will be shaken to the centre of the grate to keep a proper thickness of fire there, and coal tends to roll towards the tube plate. It therefore follows that only light firing against the tube plate is necessary.

Large quantities of coal thrown towards the centre of the grate will almost always cause heavy black smoke, which, apart from the unpleasantness, is a serious waste of coal and of the fireman's labour. As mentioned in **Section 1**, smoke consists mainly of unburned hydrocarbons. If these hydrocarbons are allowed to burn, a higher firebox temperature results, and the hotter gases passing through the tubes give the steam more superheat. It will therefore be seen that thick smoke is wasteful in all directions, and is a sign of bad firing. The condition to aim at is a very light grey smoke at the chimney while the engine is steaming, with practically none while standing or drifting. Keeping the firehole door *slightly* open after putting on a fire helps considerably to reduce smoke. The attention of enginemen is drawn to *Clause 41, Section IX of the General Appendix (Part 1).*

The blower can cause considerable damage if used carelessly, but is a most useful fitting when handled correctly. It should normally be used for the following purposes:

1. To provide a draught when building up the fire while the engine is standing.
2. To assist in maintaining the draught when the engine is pulling hard but running at a low speed.
3. To keep heat and dust away from the fireman when cleaning the fire. In this case the blower should be only *just open.*
4. To assist in preventing smokebox gases from being drawn into the steam chests and cylinders while the engine is drifting. Only a small opening of the valve is required.

In all these cases the blower should be opened only sufficiently to give the desired effect. Excessive use of the blower when the firehole door is open, draws large volumes of cold air into the firebox, and may cause rapid contraction of the plates and tube ends, and consequent leakage. Further, the cold air drawn in will tend to cool the boiler, instead of raising the pressure. Keeping the blower hard on while the pressure is low and a good fire is on the grate will cause a rapid rise of pressure, with severe stresses in the plates and stays.

When a boiler is making steam, and the smokebox and blower pipes are cold, rapid opening of the blower valve will cause dirty water to be thrown out of the chimney and to fall on the boiler and anything else nearby. There is no excuse for this carelessness.

In order that the fire may continue to burn properly, it is essential that it be kept clean, as accumulations of ash and clinker restrict the air supply seriously. The most effective way of keeping a fire clean is as follows:

1. Ensure that the openings in the grate are clear before leaving the shed.
2. Fire only sufficient coal to keep the steam pressure constant. The more coal fired, the more ash produced, and the dirtier the fire.
3. With the ashpan coolers working, the grate should be given a *light* shaking at fairly frequent intervals, and as soon as an ash section is reached, the dead ashes in the ashpan should be dropped. It must be remembered that the ashpan slides must be kept closed except at authorized ash dropping points, as detailed in the local appendices. The attention of enginemen is drawn to *Clause 38, Section IX of the General Appendix (Part 1),* and to *Train Working Regulation No 179.*
4. The pricker should be used only when absolutely necessary, and then as little as possible. Great care must be taken to prevent ash from the bottom of the fire from being brought up near the top where the fire bed is very hot, as clinker is then certain to form, because it consists mainly of partly melted ash. Clinker can also develop when the fire is built up too thick.
5. Excessive use of the blower when there is a large amount of unburned coal on the grate will also cause trouble. The fire will become clogged and clinker will develop.
6. Too much water on the coal in the bunker will cause so much steam to form in the firebox that the fire will not burn properly, and will become dirty. The coal should be sprayed lightly and only sufficiently often to keep down the dust.
7. Ash must not be allowed to accumulate in the ashpan to such an extent as to restrict the supply of air to the grate, as this will prevent the fire from burning properly and will in time cause the firebars to be burnt. Burnt firebars are almost always a result of gross carelessness on the part of the enginemen.

The ashpan coolers must be used every time the fire is cleaned. When the fire is cleaned while the engine is standing, the spray pipe can often be used to assist in quenching hot ashes and in clearing the ashpan, but great care must be exercised to avoid the jet of water coming in contact with the grate or the firebox plates. If no pit is available into which the ashes can be dropped, the pile of ashes between the rails must be levelled off to prevent its being struck by the cowcatcher of another engine, causing dust and ashes to be thrown over the engine and into the air, and dangerously restricting the view of the crew. Derailments are often caused by leaving piles of ashes between the rails.

The correct use of the injectors will make the work of the firemen much easier, and reduce possible damage to the boiler through rapid changes of pressure and temperature. When the engine is steaming, the injector should work continuously and the water cock should be so set that the correct water level is maintained in the boiler. Provided the injector is working properly, the less water supplied the hotter will be the feed to the boiler, which is always an advantage. Each injector should be used in turn, so as to keep them both in good order.

When starting or shutting off an injector, the greatest care must be exercised to see that no persons, animals or property such as goods are near enough to be injured or damaged by steam and boiling water blowing out of the overflow pipe. (See also *Train Working Regulation No 179).* The correct way to start an injector is first to turn on the water as nearly as possible to the correct amount, and then to open the steam quickly. On modern locomotives fitted with a Sellars quick-acting valve on the steam supply, the stop valve on the turret should be opened, and the Sellars valve should then be pulled fully open in one rapid movement. If the water cock is anywhere nearly correctly set, the injector will start at once, and the water can then be adjusted to the required amount. Any adjustment of the steam supply should be made with the valve on the turret, not with the Sellars valve.

To shut off the injector, the steam valve should be closed just before the water valve, as this prevents a severe blow out of the overflow, and save steam and water.

The correct water level in the boiler is from ½ to ¾ glass on level track, about ¾ to a full glass on a rising grade, and about ¼ glass on a falling grade. Too high a water level encourages priming and reduces the steam space above the water, as well as the free area of the water from which the steam bubbles can escape. Poor steaming may result from too high a water level in the boiler. Too low a water level is definitely dangerous, and can easily cause a disastrous explosion.

Firemen must always remember that coal and water cost money, and should not be wasted. Further, the less coal and water used, the easier the job will be for the fireman. From the point of view of the driver, the less the fireman has to work the more time he has to assist the driver in keeping a good look out in terms of *Train Working Regulation No 171.* A heavy discharge of steam from the safety valves is wasteful, since 'the steam that blows the whistle does not help turn the wheel'.

Priming occurs when water comes over with the steam into the internal main steam pipe. It can cause serious damage to the cylinders, and always spoils the lubrication of the front end. Excessive water in the cylinders is a common

cause of knocked out covers, cracked castings, broken piston heads, bent piston rods or damaged crossheads. In addition, priming in time damages the superheater elements, by depositing scale inside them and allowing them to become overheated.

The two main causes of priming are:

1. Too high a water level in the boiler.
2. Foaming, resulting from excessive quantities of certain salts in the boiler water.

The prevention of priming caused by (1) is simple. With regard to (2), reasonably frequent use of the blowdown and scum cocks will help greatly to reduce foaming, by keeping the concentration of salts down to a reasonable amount. In addition, certain compounds are added to the water in the tender on some sections of line, particularly where the water is treated in softening plants. The doses of these compounds are carefully worked out, and enginemen must see that they are correctly fed into the tender. To take up the attitude that the compounds are unnecessary is foolish, and may land enginemen in serious trouble. It is sometimes found, especially when the water conditions along the line change suddenly, such as after heavy rains, that the anti-foaming compounds do not give normal results. In such cases enginemen must immediately report to the Locomotive Foreman, giving all the information possible, so that the chemist may be able to deal with the matter without delay.

When using blowdown cocks, whether the engine is standing or moving, certain precautions must always be observed. These are:

1. Ensure that persons or animals are not endangered by the escaping steam and water.
2. Damage to material or structures must be avoided.
3. Where the boiler is fitted with two blowdown cocks, these should be used alternately.

Heavy blowing down for long periods is harmful to the boiler, is rarely necessary, and wastes coal and water. Blowing down for short periods once or twice on a trip is usually quite sufficient, except in areas where the water is bad, in which case it may be necessary rather more often. It is a good practice to blow down the boiler just before the engine leaves the running shed for the traffic yard, as the concentration of salts is then normally higher than on the completion of the previous trip. Some running sheds and water stations are provided with special paved areas for blowing down, and at such sheds and stations care must be taken not to blow down boilers except in these areas.

It is always important to remember that the driver is solely responsible for blowing down the boiler, and he must give this operation his full attention.

He should ensure that there is ample water in the boiler and in the tender, and that the injectors are shut off. The blowdown cock should first be tested by opening and closing it slightly several times, and the lever should then be moved slowly until fully open. The cock should be closed slowly, as otherwise there is a danger of water hammer damaging the cock or its fastenings.

The correct procedure to be followed when cleaning or dropping the fire over the ashpit at the Running Shed, after completion of a trip, is as follows:

1. With the leading vacuum pipe properly on the dummy, the smokebox must be cleaned before the fire is cleaned or dropped, and the smokebox door must be closed immediately the cleaning of the smokebox is completed. The front platform must then be brushed clean.
2. The boiler must then be filled by means of the injectors until the water level in the gauge glasses reaches the bottom of the top gland nut.
3. If the locomotive has to be moved some distance before it is finally stabled, it is essential that the steam pressure should be raised to the maximum permissible, without the safety valves being allowed to blow off. This is particularly necessary where duties such as the coaling of the tender have to be undertaken after the fire is dropped.
4. The blower valve should be *slightly* opened, so as to keep the heat and dust away from the servant cleaning or dropping the fire. The blower valve *must not* be opened fully, as this will allow large volumes of cold air to be drawn through the boiler, with consequent uneven contraction and damage to the firebox and the tubes.
5. The fire must then be cleaned or dropped, as required, as quickly as possible, with the ashpan coolers working, and the slides open.
6. *Immediately* this is completed, the blower valve must be fully closed, and the firehole door, ashpan slides, dampers (where provided) and grates must be closed.
7. Where cold water jets are used for washing down the ashpan while cleaning the fire, great care must be exercised to prevent the water from striking the hot firebars or firebox plates.
8. When the fire is not dropped, but merely cleaned, and the locomotive is not required for traffic within a short time, the fire should be banked in the *front* of the firebox under the brick arch, and the firehole door, ashpan slides and dampers (where provided) must be closed.
9. The movement of locomotives under their own power, after their fires have been dropped, must be restricted to the absolute minimum. Carrying out shunting movements with engines without fires is extremely harmful and must not be permitted.
10. Where no ash pit is provided, as at certain small sub-depots, the engine should be moved forward from time to time while the fire is being dropped or cleaned, care being taken to see that any live fire dropped is extinguished, and that the hose connections between the engine and the tender are not damaged. The advantage of moving forward rather than

backward is that ash and dust do not settle on the motion to any great extent. The engine should always be stabled clear of the area where the fire is dropped.

11. It is always a great advantage to bank the fire rather than to drop it, whenever possible. The boiler is kept warm while the engine is stabled, and less time and labour is required to prepare the engine when it is next required for traffic. The cost of the coal burnt while the fire is banked is small compared with the reduction in possible damage to the boiler.

The attention of all concerned is directed to *Clause 42, Section IX of the General Appendix (Part 1).*

When it is necessary to blow the steam out of the boiler, the following procedure must be adopted:

1. Once the fire has been dropped, the injectors should not be used for filling the boiler unless absolutely necessary. During the process of blowing off the steam, great care must be taken that the firebox crown remains covered with water. If the water is near the top gland nut in the water gauge when starting to blow off the steam, it will normally be found that a quarter to a third of a glass of water is left when the steam is all out.
2. The steam pressure must then be reduced gradually to zero by blowing off over a period of at least two hours. The steam must be released through the release valve mounted on top of the boiler, or, if this is not provided, through the injectors. Care must be taken to see that the pressure does not fall too rapidly at first.
3. On no account must the water be drained from the boiler while it is still under pressure.

Enginemen and shed staff must take every possible precaution to prevent cold air from being drawn through hot boilers, by seeing that the firehole door, ashpan slides and dampers (where provided) are properly closed except when they *have* to be opened, and by using the blower with great care. The quickest way to cause serious damage to a boiler is to allow large volumes of cold air to be drawn through it while it is hot. This results in rapid contraction of the firebox plates, particularly where they are joined together. It also makes the tube ends and stay heads contract, and is the most common cause of leaks.

The causes of bad steaming of a locomotive boiler are many and various, but most of them can be traced to restriction of the draught or of the air supply to the fire. There are other causes, however, and these will be dealt with first.

Heating surfaces coated with scale or mud, particularly around the inner firebox and the first few feet of the tubes, seriously interfere with the transmission of heat through the metal, as scale is a bad conductor of heat. In the same way, heating surfaces covered with soot on the fire side give

considerable trouble. Soot is caused by incorrect firing, which itself often results in poor steaming, particularly if holes are allowed to form in the fire.

Dirty water in the boiler, causing, foaming and priming, and too high a water level are other causes of bad steaming. Incorrect use of the injectors also often results in poor steaming.

With regard to draught restrictions and air supply, anything which prevents sufficient air coming through the grate will result in bad steaming. Probably the most common causes are too thick a fire, clinker, choked or defective firebars, a choked ashpan, and a defective brick arch.

Anything which prevents sufficient vacuum from being created in the smokebox will always cause poor steaming. The most common of these defects are elements or steam pipes blowing or burst, steam joints blowing, and the smokebox drawing air. Others are blast pipe or chimney incorrectly aligned or loose, blast pipe cap defective or choked with carbon, blast pipe cap too large or too small, or at the wrong distance from the throat of the petticoat, exhaust pipes and passages choked or defective, and boiler tubes blowing.

Even when there is ample vacuum formed, serious trouble can be caused if the path of the gases from the firebox to the chimney is restricted. Choked. tubes and dirty spark arrestors are the principal reasons for this.

Tubes leaking in the firebox, and stays or seams blowing will always affect the steaming to some extent, sometimes seriously, but if dealt with promptly, leaking tubes can often be made to take up sufficiently to avoid loss of time on the road.

When an engine is found to be steaming badly, every effort should be made to find the cause of the trouble and, if possible, to remedy it. The tendency is to fire more heavily, but this nearly always makes matters worse, as a thick fire in itself restricts the air flow through the grate, apart from encouraging the formation of clinker. It is normally better to fire more tightly than usual, and to keep the fire as thin and as bright as possible. When an engine steams badly, the closest co-operation between the driver and the fireman is essential.

The first defects to look for on an engine which steams badly are a choked ashpan, defective grates and a thick, uneven or clinkered fire. If these are all in order, examine the spark arrestor plates, which are possibly choked, failing which the smokebox should be tested with a torch lamp for air leaks. The most common place for the smokebox to draw air is around the door, and if this goes on for any length of time the cinders in the smokebox will catch fire and will burn the door and the smokebox front. Should this happen, the

smokebox must be cleaned out immediately, and after the door has been closed as tightly as possible, asbestos mixed with grease or oil from the engine framing should be packed around the edge of the door. Asbestos can nearly always be obtained from the steam heating pipe on the tender or on a coach.

If the tubes are found to be leaking in the firebox, the only thing to do is to raise the temperature of the fire and the gases as much as possible. This is best done by keeping a thin bright fire, and not opening the firehole door any more than is absolutely necessary. The door should be worked when firing. Tubes which are not leaking badly can often be made to take up in this manner, but whether they are dry or not by the time the engine reaches the running shed, the defect must be booked.

Once tubes become dirty or badly blocked there is little that enginemen can do to clear them on the road. A fire which burns fairly well while the engine is steaming, but which will not burn, properly when the regulator is closed, is a fairly good indication of dirty tubes or choked spark arrestors.

Steam blowing into the smokebox from elements, steam pipes, or their joints is easily detected, but it is not always possible for enginemen to locate the exact defect, as the spark arrestor restricts the view. In such a case the blow must be booked as accurately as possible. An immediate report must be made on arrival at the running shed, as this will sometimes enable the defect to be found and remedied without the necessity of cooling down the boiler.

A loose or blown-out blast pipe base joint is easily found by heaping ash around the joint, applying the engine and tender brakes, and opening the regulator slightly while moving the reversing lever from fore-gear to back-gear a few times.

A defective blast pipe cap or the blast pipe or chimney out of line can be seen by the smoke and exhaust steam not filling the chimney properly while steaming.

When booking the fact that the engine will not steam, the driver must be sure to give the reason. If the driver cannot find the cause of the trouble after testing everything possible he must make a special report to the Locomotive Foreman, giving all the information he can. Merely booking 'Engine will not steam' is an almost certain sign of incompetence or laziness. The defects in water gauges which may occur on the road are (**1**) broken or choked glass, and (**2**) choked water or steam passages. The correct way to deal with these is as follows:

1. Shut off steam and water cocks, and open the test cock. Remove the cavity plug at the top of the steam cock, and take out the reducing valve. Loosen the packing nuts and the glands and remove the old glass and the

packing, and thoroughly clean out the recesses at both ends. Open the water cock slightly to blow out any pieces of packing which may have lodged in the recess or in the water passage, and then place the packing nuts and the glands on each end of the glass together with the rubber washers. Fit the glass into the recesses and put a small piece of wood or cork on top of the glass, and replace the cavity plug. This prevents the glass from lifting when the packing is tightened up, and avoids the possibility of any packing working under the glass in the water cock. Next place one turn of asbestos string which has been moistened with water around the glass in the upper and the lower recesses, and screw the packing nuts up by hand, thus forcing the asbestos and the rubber washers into the recesses. One or two turns of the packing nuts with a spanner is then all that is required to tighten the glands firmly. Then take out the cavity plug, remove the wood or cork, and replace the reducing valve and the cavity plug. Before opening any cocks, *replace the protector,* and then open the water cock slowly and allow the water to fill the glass. When the glass is full, wait for several minutes to allow the glass to warm up thoroughly, and then open the steam cock. After this, the water gauge should be tested properly, as already described in this Section. If the glands are found to be leaking, it is essential to close both the steam and the water cocks, and to open the test cock before the gauge glass protector is removed, and after tightening up not to open the steam or water cocks before replacing the protector.

2. If it is suspected that a steam or a water passage is choked, and the engine is away from the running shed, the passages must be cleared. The steam and the water cocks should both be closed, and the test cock opened. Then remove the cavity plug and the reducing valve, and the cleaning plug in front of the steam cock. Stand well clear, open the steam cock slowly, and work a piece of wire into the passage. When the passage is clear the steam will blow freely, and the cock should then be closed, and the reducing valve, cavity plug and cleaning plug should then be replaced. The procedure in the case of the water cock is the same, except that there is no cavity plug or reducing valve to be removed, and the ball will have to be taken out before the wire can be inserted.

After clearing the passages, the water gauge must be tested to ensure that everything is in order.

There are several defects which may occur in injectors and their connections, the most common of these being **i.** air tight tender lid; **ii.** blocked water ways or strainer; **iii.** pipe joints blown out; **iv.** cones dirty or obstructed; **v.** cones worn; **vi.** combining cone loose; **vii.** clack valve obstructed or with insufficient lift; **viii.** clack valve blowing through; **ix.** injector hot or hot feed water.

The usual indications of these defects and the methods of dealing with them are as follows:

i. & **ii**. These will be indicated by little or no flow of water from the overflow pipe when the water valve is opened, and ability of the injector to pick up when the steam valve is opened. On tenders not fitted with breather pipes, ice can easily make the lid air tight in cold weather, and air will not be able to enter the tank to replace the water as it is used. The lid should be left slightly open to overcome the difficulty.

If the tender lid is not air tight, the trouble must be in the water ways or the strainer. On most modem locomotives the strainer is in a casting just below the tender, and can be removed by taking off the side cover. On older locomotives the strainer is inside the tender, and it is then necessary to blow back by plugging the overflow and opening the steam valve slightly, being careful not to blow out any of the joints. This remedy is only a temporary one, and the tender should be booked for cleaning out on arrival at the running shed.

i. Blown-out pipe joints are obvious, and a vacuum washer often makes a good temporary joint.

ii. If steam and water blow out of the overflow, the injector will not pick up, and there is no 'rattling' in the delivery pipe, the cones are most probably obstructed. To clear them, remove the cap and screw from the delivery cone and withdraw the suction cone. Any obstruction can then be removed, but care must be taken not to damage the cones, particularly the sharp edges of the steam and suction cones.

Dirty cones are not so easily detected, but usually the injector will overflow slightly whilst working, and will be difficult to start.

iii. An injector with worn cones will work with a low steam pressure, but will not work when the pressure rises. This is also an indication of a clack valve with insufficient lift, or a partially blocked distributor nozzle. If throttling the steam supply to the injector does not help, the only thing to do is to reduce the boiler pressure until the injector picks up.

iv. A loose combining cone will drop on to the suction cone, closing off communication with the overflow, and when the water and steam are turned on, steam will blow back into the tender. The combining cone should be pushed back into position, after removing the delivery and suction cones, and the set screw should be tightened up or replaced if possible. It is often possible to get at the combining cone by removing the overflow pipe.

v. Insufficient lift in the clack has been dealt with under **v.**, but if the clack is obstructed there will normally be a rattling sound in. the delivery pipe. The same will occur if the stop cock were shut off. If the clack is obstructed, the stop cock should be shut off, the vent

screw slackened back to release the pressure in the clack box, and the cap should then be removed. It will then usually be possible to clear the obstruction.

vi. A clack valve blowing through slightly is indicated by a hot delivery pipe, together with a discharge of steam and an intermittent discharge of water from the injector overflow, usually accompanied by a gurgling sound. If the injector steam and water valves are both leaking, the discharge will be steady, and the delivery pipe will not be hot. Sometimes starting the injector will clear away whatever is holding the clack open, but if the valve or its seat are defective, nothing can be done on the road except to shut off the stop cock if the blow is serious. If there is a heavy discharge from the overflow when the injector is shut off, the clack has stuck open. Often a light tap with a hammer, on the clack box cap will reseat the valve, but if this does not work, the stop cock should be closed and the clack box opened as described in **vii.** The valve can then be re-seated. If the stop cock will not move, even if the gland nuts are slackened, the only thing to do is to throw out the fire. With the usual type of double clack box on top of the boiler, starting the other injector will sometimes reseat the clack which has stuck open.

Most modern locomotives are fitted with a non-return valve in each injector delivery pipe, near the injector, mainly to avoid the considerable loss of water from a long delivery pipe when the injector is shut off. Enginemen should see that these valves are in order, and if the interior has been removed, as sometimes occurs, should insist that it be replaced, as if these valves are working they are of great use when clack valves become defective.

vii. A blowing clack or injector steam valve will often make the injector so hot that it will not pick up, because the water does not condense the steam properly. Hot feed water in the tender has a similar effect. If a valve is blowing, the injector can usually be cooled sufficiently by pouring water over it, or wrapping a wet sack around it.

WORKING OF MECHANICAL STOKER

After coming on duty, the responsibilities of the driver as far as the mechanical stoker is concerned, are as follows:

1. See that the correct oil level in the stoker engine sump is shown on the dipstick. If the level is not correct, the fitter or other servant responsible for lubrication should be called at once.
2. See that the open portions of the stoker are in good order.
3. Fill up the oil cup on the left hand side of the tender bunker opening, and see that the trimmings are in good condition. Use the soft grease gun on the nipple next to the oil cup.

4. Fill and start the hydrostatic lubricator, and set the stoker feed as nearly as possible for three drops per minute. As this feed will not work for long while the stoker engine stop valve is closed, it will need final setting later.
5. Ensure that the fire is *thoroughly clean,* and build up a substantial level bright fire by spreading coal evenly all over the grate with the shovel. The fire bed must be thick enough to resist any tendency to pull under the brick arch when starting a heavy train, but should not be as thick as would be necessary on a hand-fired engine. The mechanical stoker should *not* be used for building up the fire, either before a trip or while awaiting a crossing along the road. The ashpan must be thoroughly clean.
6. Make sure that the stoker engine stop valve and the booster valve are shut and open the stoker jet main steam valve on the turret. Then open the main jet valve very slightly to drain any water from the steam pipe.
7. As soon as the manifold has warmed up, open the main jet valve fully and then test each of the five jets by opening and closing the five valves in turn, and use the jet pricker to make sure that the holes above the distributing table are clear, not forgetting that the fine coal jet has four holes, which are the lower ones, and the front corner jets have two holes each, above those for the fine coal.
8. See that the stoker engine reversing valve is in the 'forward' or fully down position, and then open the turret valve fully and the stoker engine stop valve very *slightly,* and wait for the stoker engine to warm up, noting meanwhile whether the automatic water drain valve is discharging properly. While the engine is warming up, set the lubricator feed correctly to give three drops per minute.
9. Set the jets as follows. With the turret valve and the main jet valve fully *open,* set the front comer valves to give a pressure of about 20 lb per square inch, and open the back corner valves half a turn. Keep the fine coal valve closed.
10. Set the adjustable vanes as follows. Stand with one foot on each side of the elevator, and look straight at the distributing table. If it is assumed that the front corners of the distributing table represent the 9 and 3 o'clock positions on a clock face, the front ends of the vanes should be in line with the 10 and 2 o'clock positions.
11. The stoker engine should by this time have warmed up, and if there is no large escape of water from the automatic drain valve, open the front tender slide, and open the stoker engine valve until the gauge shows about 25 lb per square inch. Shut off the blower, and with the firehole door open, watch the distribution of the coal over the firebed, making any adjustments necessary to the jets or the adjustable vanes. No more than slight adjustments should be required.
12. The stoker should be shut down as soon as it is clear that everything is in order, and should not be used again until the commencement of the trip.

During the trip, the stoker should normally be used while the locomotive is steaming, and should be stopped while drifting, but circumstances will sometimes alter this. A fairly thin bright fire of even thickness is necessary if good results are to be obtained, and the jet valves and/or the vanes should be adjusted if the fire is uneven. Large volumes of black smoke indicate that the firing is too heavy or is uneven, and this must be corrected at once or the steam pressure will drop.

Five important points to remember are:

a. That the coal burns to a considerable extent before it falls on the firebed and that while steaming the firebox should be completely filled with yellow flames.
b. The distributing table determines the direction in which the coal will be thrown.
c. The jets control only the distance the pieces of coal are thrown.
d. The adjustable vanes control the amount of coal fed to the back corners of the firebox.
e. The speed of the stoker engine determines the speed of the conveyor, and hence controls the firing rate.

Great care must be taken to prevent the fire from banking up under the distributing table, as if this should happen the table will soon become warped and burnt. The grates should be operated at fairly frequent intervals to prevent the formation of clinker, but care must be taken not to shake the fire down too low, as the fire bed is thin. The stoker engine must be stopped while the grates are being operated, to avoid unburned coal falling directly into the ashpan. The ashpan cooler *must* be used when the fire is shaken, and it is essential that the sides of the ashpan be kept clear of ashes, as otherwise the supply of air to the fire will be inadequate and uneven.

Once the jets and the vanes have been correctly set, further adjustment should not normally be necessary. When the stoker is working, the main jet valve should be fully *opened,* and should not be used for throttling the steam supply to the jets. If it is noticed that the coal tends to bank up on the distributing table, the jets should be cleaned with the jet packer and if necessary the 'fine coal' jet should be opened just sufficiently to clear the coal. Care must be taken that the fine coal jet does not bank the fire against the tube plate, as the draught will be restricted in that area, and the fire towards the back of the grate will tend to be pulled under the brick arch. The feeding of the coal on to the distributing table should be closely watched to ensure that the correct rate of feed is maintained. The spray pipe should be used often enough to keep down dust, but should not be kept on for long at a time. If the fine coal is washed into the conveyor in the form of a pulp the feed will be irregular and the jets will not distribute the coal correctly. Only one conveyor slide should be open at any one time.

Before taking coal, whether at the depot or along the road, all the conveyor slides must be closed, so that the coal does not fall directly into the trough. When stabling the locomotive, the slides should be closed, and the stoker engine should be run long enough to clear the whole conveyor system of coal.

At all times while the locomotive is in steam and the stoker is not working, a little steam must be allowed to blow through the jets to keep the distributing table cool. Most main jet valves are provided with a bleed hole to supply this steam while the main valve is closed, but where this is not so, the main valve should be just cracked.

STOKER DIFFICULTIES

The most common difficulty experienced is hard lumpy coal. The stoker engine will slow down and the pressure on the engine gauge will rise. Use of the booster valve will often crush the hard lumps, but this valve should never be kept open longer than is necessary.

If the stoker engine stops, there is probably a piece of stone or metal in the crushing zone of the conveyor. The stoker engine valve should be shut, and the reversing valve should be operated. If the stoker will not run forwards after two or three reversals, it should be run backwards until the obstruction appears opposite the open slide. The stoker engine valve must then be shut, and the reversing valve must be placed in the neutral or centre position, and the obstruction should be removed by hand. Enginemen should never enter the tender unless the stoker is shut off and the reversing valve is in the neutral position. Great care should be taken to prevent coupling pins, links, fish plates, lumps of rock or other foreign matter from getting into the conveyor, and if such objects are detected they should be removed without delay. The reversing valve must never be operated unless the stoker engine stop valve is shut off.

If the fire is pulled away from the back of the firebox, the conveyor should be run with the front comer jets, the fine coal jet and sometimes also the back comer jets shut off, and further assistance in rectifying the fire should be given with the shovel. If the stoker engine or the conveyor were to fail, the engine must be fired by hand, but considerable help can usually be obtained by using the jets and placing the coal on the distributing table by hand.

While the mechanical stoker makes the job of the fireman much easier, it is essential that constant attention be given to the stoker and to the fire. Defects in firing show up quickly on stoker fired locomotives, because there is not a thick enough fire on the grate to keep up steam for long.

SECTION 10

TESTING VALVES & PISTONS

Port openings. Definition of a 'blow'. Running blows. Fundamental points for locating blows. Additional indications. Blows for outside admission piston valves. Additional blows for slide valves. Standing tests. Normal procedure. Details of tests for valves, bye-pass valves, steam & exhaust port edges and piston rings, right & left-hand sides. Fundamental points. Exhaust clearance on valves & exact position of valve. Position of big end when piston is in centre of stroke. Distinguishing between defective bye-pass valve & steam port edge. Making a steam chest of a cylinder. Leading crank pin not clearing crosshead. Example of a standing test. Several parts defective simultaneously. Examination of valve rings. Tests for defective valve strips. Booking of valve & liner or false seat. Testing of Garratt locomotives. R.C. valve gear. Mid-gear test. Tests for individual exhaust valves. Test for steam valves & piston rings. Sticking exhaust valves.

When testing valves and pistons for defects or 'blows', either while running or when standing, it is essential to know which ports are open to steam, which are open to exhaust and which are closed. The position of the piston in the cylinder and the cut-off in which the reversing gear is set together determine the port openings. Tests when standing should always be carried out with one big end placed on the bottom quarter or on the top quarter, although the former is preferable as with the big end on the bottom quarter the front port will be open to steam in fore-gear and the back port in back-gear. In **Section 5** some examples of port openings are given, as well as examples of the relative positions of the cranks. Detailed descriptions of the cylinders, ports, and various types of valves and valve gears are also given in **Section 5**, which should be carefully studied before attempting to test valves and pistons, as it is essential to know without any doubt which ports are open and which are closed.

A 'blow' may be defined as an escape of steam to exhaust and up the chimney at a time when there should not be any noticeable escape. Blows may sound like anything between a squeak and a loud roar, and if they can be identified even approximately while the engine is running, much time will be saved when carrying out a standing test.

If a blow is heard while the engine is steaming, it is normally easier to identify it by running fairly slowly with the reversing lever in full gear, rather than at a short cut-off. Assuming the engine is running forwards, the port openings of either cylinder in full gear are shown in the diagram, **Fig 99**, for a valve without exhaust clearance.

The front port opens to lead steam just before the big end reaches front centre, and in full fore-gear it remains open until the big end reaches the bottom back angle. The front port opens to exhaust a short time before the big end reaches back centre, and remains open until the big end is a similar distance from front centre. The vents for the back port are similar, and are also shown on the diagram.

To spot the position of the big end while running, takes practice, but is quite easy for anyone with some experience.

RUNNING BLOWS

An engine fitted with inside admission piston valves and bye-pass valves will first be considered, as this may be regarded as the normal standard arrangement on the S.A.R. As the driver's seat is on the right hand side of the engine, it is convenient to relate running blows to the right hand side.

Certain fundamental points must always be remembered when locating blows, particularly running blows. These are:

1. A blow starting when the right hand big end is on (or very near) front or back centre comes from the right hand side.
2. A blow starting when the right hand big end is on (or very near) top or bottom quarter comes from the left hand side.
3. A single blow per revolution of the wheels is caused by a defective exhaust port edge or by a defective steam port edge or a bye-pass valve.
4. Two blows per revolution of the wheels are almost always caused by defective piston rings on one side.
5. A continuous blow is caused by either a seriously defective valve or by defective piston rings on both sides.
6. A defective steam port edge or bye-pass valve blows when the valve is open to exhaust at that end, and a defective exhaust port edge blows when the valve is open to steam at that end. This applies equally to running and standing tests.
7. In full gear a blow will usually last from the time the big end on that side passes the dead centre until it passes the angle, of a stroke ahead.

Additional indications which help to identify running blows are as follows:

1. A defective exhaust port edge does not cause additional back pressure, and although most of the power on the particular stroke affected will be lost, it is usually possible to keep going, with a reduced load if necessary.
2. A defective steam port edge or defective bye-pass valve will give very early admission, in fact from the point where the valve closes the

exhaust port, and at fairly low speeds this may be sufficient to lock the engine. The effect will be much more serious if the defect is bad than in the case of a broken exhaust port edge.

3. An unusually heavy exhaust beat without any actual blow indicates a later cut-off than there should be on that end of the cylinder concerned. This is usually caused by defective admission rings on the valve head or by a slightly damaged steam edge of the valve or port.
4. Defective exhaust rings on the valve head give a squeak like a blowing gland, just before the exhaust beat at slow speeds. At high speeds the exhaust beat has a peculiar bark, quite different from the usual sound. The pulling of the engine is liable to become jerky when running at short cut-offs.
5. It is usually possible to distinguish between a seriously defective valve, and defective piston rings on both sides. While in full gear the blow will be continuous in either case, in a short cut off of about 30 per cent defective piston rings will give four blows per revolution of the wheels at fairly low speed, but a broken valve will give a continuous blow in all positions of the reversing gear.

Blows for a locomotive with outside admission piston valves and bye-pass valves are exactly the same as for one with inside admission valves and bye-pass valves. Engines equipped with slide valves do not have bye-pass valves, but otherwise blows are the same as for a piston valve with three additions.

These are:

1. A canted valve, caused usually by excessive priming. This is indicated by a heavy continuous blow which starts suddenly, and can often be rectified by moving the reversing gear rapidly from fore-gear to back-gear and back again several times while the regulator is slightly open.
2. A cut valve, false seat, or both valve and seat also gives a continuous blow, but this develops slowly, and is normally not nearly as heavy as for a canted valve.
3. Valve strips blowing give a continuous squeaky blow while running, but it is usually possible to distinguish this from a slightly cut valve or seat by watching the valve motion. If the strips are blowing more than very slightly the motion on that side will move jerkily and will tend to get hot, on account of the increased load on the valve.

STANDING TESTS

Any blows identified while running should always be confirmed by standing tests, and in any case standing tests are essential if the blows have not been located while running.

The normal method of carrying out standing tests is as follows:

1. Place the big end on the side suspected of being defective on bottom quarter.
2. Put all brakes hard on, and scotch the wheels to prevent movement either forwards or backwards.
3. Shut off all auxilliary steam to the cylinders and to the smokebox, i.e., lubricator, drifting valve, blower and vacuum ejector.
4. Place the reversing lever in mid-gear and open the cylinder cocks.
5. Open the regulator slightly and build up a good pressure in the steam chests.
6. After noting the indications in mid-gear, fore-gear and back-gear, remove the scotches and place the other big end on bottom quarter and repeat the test.

Consider an engine with piston valves and bye-pass valves and suppose the test is started on the right hand side, and that there is no knowledge of any running blows. The right hand big end must be placed on bottom quarter, and points **2**, **3**, **4**, and **5** of the normal procedure mentioned previously must be carried out.

If there is no blow up the chimney, and no blow from the right hand cylinder cocks, it indicates immediately that the following parts are in good order on the right hand side, as that valve is central over the ports, valve heads, steam port edges, bye-pass valves. On the left hand side the big end will be on front centre, the front port will be open to lead steam, and the back port to exhaust. Steam must therefore appear at the front cylinder cock, but if there is no blow up the chimney and no steam from the back cock, the following parts are in good order:

- valve heads
- front exhaust port edge
- back steam port edge
- back bye-pass valve
- piston head and rings

The reversing gear should then be placed in full fore-gear, thus opening the right hand front port to steam, and the right hand back port to exhaust, but *not* altering the position on the left hand side, where the front port remains open to lead steam and the back port to exhaust in *all* positions of the reversing gear. It therefore follows that if there was no blow from the left hand side in mid gear, the tests in fore-gear and back-gear will apply to the right hand side only.

On the right hand side, steam will appear at the front cylinder cock, as the front port is open to steam. If there is no blow up the chimney, and no steam appears at the back cylinder cock, it indicates that the front exhaust port edge and the piston head and rings are in good order. Placing the lever in

back gear will open the back port to steam and the front port to exhaust on the right hand side, thus testing the back exhaust port edge. If there are no defects on the right hand side, a single well defined beat will be heard as the reversing lever is moved from fore-gear to back-gear.

It must be remembered that there are still certain parts on the left hand side which have not yet been tested. These are the front steam port edge, front bye-pass valve and the back exhaust port edge. The left hand side must now be placed on bottom quarter and when the reversing lever is in mid-gear the front steam port edge and the front bye-pass valve will be tested. The only remaining item is the back exhaust port edge, and to test this the reversing lever must be placed in back-gear, thus opening the back port to steam.

The fundamental points in all these tests are:

1. That a defective steam port edge or bye-pass valve will cause a blow to the chimney only when the port concerned is open to exhaust.
2. A defective steam port edge or bye-pass valve will cause steam to appear at the cylinder cock at that end of the cylinder when the reversing lever is in mid-gear, and the crank is on bottom quarter.
3. A defective exhaust port edge will cause a blow only when the port concerned is open to steam.
4. With the big end on bottom quarter, defective piston rings will blow in *both* fore-gear and back-gear, but not in mid-gear.
5. That if an exhaust port is open either because of the position of the valve or on account of a broken exhaust port edge or valve head, the steam will escape up the chimney and it is most unlikely that any steam will appear at the cylinder cock at that end.

A point to bear in mind is that exhaust clearance is provided on the valves of many of the older locomotives, so that with the crank on bottom quarter and the reversing lever in mid-gear both ports on that side will probably be very slightly open to exhaust. Another point is that it is difficult to set an engine with the piston *exactly* in the centre of its stroke, and that there is often a certain amount of lost motion in the valve gear, so that it is not possible to guarantee that in the mid-gear position the valve will be precisely central over the ports. The steam lap of the valve will look after any slight discrepancy as far as the steam port edges are concerned, but there is no exhaust lap to cover the exhaust port edges.

When the piston is exactly in the centre of its stroke the big end will be slightly ahead of top or bottom quarter. The reason for this is that the connecting rod is of a fixed length, and if it were removed from the crank pin, and the centre of the big end were placed exactly in line with the centre of the driving axle, the piston would be in the centre of its stroke. If the crosshead and piston are not moved and the big end is lifted or lowered until it meets

the crank pin, the big end will be swinging on a portion of a circle, with the gudgeon pin as the centre, so that the crank pin will have to be slightly ahead of top or bottom quarter to meet the big end. **Fig 100** shows the position.

It will have been noticed that the steam port edge and the bye-pass valve at one end of either cylinder have been grouped together in all the tests so far described. The indications given by defects in these parts are the same, and to verify which is faulty the only satisfactory method is to shut off the bye-pass valve. This can normally be done by slackening off the check nut and screwing up the adjusting screw, which passes through the cover of the bye-pass valve. If this does not stop the blow, the reason may be that the valve is held off its seat by dirt, or that it has canted or broken, and it is therefore necessary to remove the cover and the valve, and reseat it. Before removing the cover it is essential to shut the regulator, and to allow sufficient time for all the steam in the elements, steam pipes and steam chests to escape. Broken steam port edges are rare compared with defective bye-pass valves. If after shutting off the bye-pass valve a blow still occurs, it must be coming from the steam port edge, and if it is bad the engine may not be able to run. The remedy then is to make a 'steam chest' of the cylinder concerned as follows:

1. Shut off all steam to the cylinder, and open the cylinder cocks.
2. Remove the connecting rod, and push the crosshead and piston as far as they will go to the good end of the cylinder, and secure the crosshead in this position.
3. Centralize and secure the valve.
4. Remove the cylinder cock at the good end of the cylinder, where the piston is now secured and close the other cock.
5. Shut off the lubricator feeds to the defective side.
6. Proceed on one side.

The way to remove a connecting rod and to centralize and secure a valve are fully described in **Section 11** (Breakdowns).

If the front steam port edge is broken, great care must be taken before moving the crosshead and piston to the back end of the cylinder to ensure that the leading crank pin will clear the crosshead. On some locomotives this is not so, with the result that if a steam chest is made with the piston at the back end of the cylinder it will be necessary to uncouple and carry the leading wheels. As this is normally a job for the breakdown gang, it is almost always better in such circumstances to fail completely and to arrange for the locomotive to be hauled home.

As an example of a standing test, consider the case of a locomotive having piston valves and bye-pass valves, and where there is no knowledge of any running blows. Assume that the left hand big end is placed on bottom quarter, the brakes are hard on, the wheels scotched and all auxiliary steam

is shut off, as previously described. With the reversing lever in mid-gear and the cylinder cocks open, a heavy blow up the chimney is heard as soon as the regulator is opened, but no steam appears at the cylinder cocks on the left hand side. The defect must now be looked for on the right hand side, where the big end is on back centre, the back port is open to lead steam and the front port to exhaust.

The possible defects on the right hand side are: valve heads, back exhaust port edge, front steam port edge, front bye-pass valve or piston rings.

To locate the blow finally, it is necessary to move the engine so that the right hand big end is on bottom quarter. With the reversing lever in mid-gear, if there is no blow up the chimney and no steam appears at the cylinder cocks, the valve heads, steam port edges and bye-pass valves are definitely sound, so that only the back exhaust port edge and the piston rings remain to be tested. If the reversing lever be now placed in fore-gear, and a blow is heard the right hand piston rings must be at fault, as the back exhaust port edge cannot blow in this position.

Should a blow have been heard when the right hand side was placed on bottom quarter, but no steam appeared out of the right hand cylinder cocks, the blow was almost certainly coming from the left hand piston rings, which had not been tested before, so that in such a case both side piston rings should be booked.

Broken front and back exhaust port edges on one side will give the same indications as defective piston rings on that side, but it is extremely improbable that both exhaust port edges will break together. Any test may fail to give conclusive information when several different parts are defective at the same time. See *Clause 45(4), Section IX of the General Appendix (Part 1).*

The valve rings can easily be seen by removing the inspection caps and shifting the valve backwards and forwards with the reversing gear. If any of the rings appear black they are defective and should be booked. If they are polished there is not likely to be anything wrong with them.

The tests for a locomotive with slide valves are the same as for one with piston valves, except that there are no bye-pass valves. To test for defective valve strips, place the big end on the side suspected on bottom quarter, and reverse the engine a few times with the regulator open. A continuous squeaky blow will be heard, and the reversing gear will be very stiff to move. Now set the suspected side with the big end on front or back centre, and reverse the engine again a few times with the regulator open. The reversing gear will move easily unless the valve strips on both sides are defective. Another test

for valve strips which is sometimes quite effective is to place the big end on bottom quarter, the reversing lever in mid-gear and close the regulator tightly. The valve is now central over the ports, and if the blower is put on, a partial vacuum will be formed in the smokebox and in the exhaust passage from each steam chest. If the valve strips are defective, air will be drawn past them, through the release port in the valve and into the exhaust passage, so that if the snifter valve be held open by hand, the flame of a torch lamp will be drawn into the air holes in the snifter valve body.

It must always be realized that the necessary steam tight joint is formed by the valve and the seating over which it slides. In the case of a piston valve the seating concerned are the steam chest liners, and for a slide valve, the false seat. If a valve is suspected of blowing through, it is essential to book both the valve and its seating for examination. This does not involve any extra work for the shed staff, as the valve must be removed from the steam chest for examination, thus exposing the liners or false seat as the case may be.

When testing the valves and pistons of a Garratt locomotive no reliable indications, except those from the cylinder cocks, can be obtained while all the pipes are coupled up and steam is being supplied to both units. If isolating valves are fitted and are in working order, it is a simple matter to shut off the steam supply to on unit at a time. On locomotives without isolating valves, probably the easiest method of testing is to uncouple the exhaust pipe of the trailing unit underneath the boiler cradle. The leading unit will then exhaust through the chimney, and the trailing unit will exhaust direct to the atmosphere underneath the boiler, so that blows from either unit are easily separated. Great care must be taken to secure the uncoupled exhaust pipe firmly before the locomotive is moved even the slightest amount. This method of testing should normally be used ,only in a running shed.

Locomotives fitted with R.C. valve gear must be treated rather differently from those with either piston or slide valves. The R.C. valve gear is described in **Section 5**, and it must be remembered while testing that in the mid-gear position all the steam valves are held fully open, and all the exhaust valves are fully closed, no matter at what point the cranks are standing. Further, bye-pass valves are not fitted.

The first test is therefore in mid-gear, with the cylinder cocks closed. If there is a blow up the chimney, one or more of the exhaust valves is faulty, and if there is no blow, all the exhaust valves are definitely sound. To locate a defective exhaust valve, place the right hand big end on bottom quarter. The left hand big end is then on front centre. Scotch the wheels, apply all brakes and with the reversing gear in 35 per cent fore-gear, open the regulator. The left front steam valve will be open to lead steam and the right front steam valve and both back steam valves will be closed, while both front exhaust

valves will also be closed. If there is no blow in this position, the left front exhaust valve and the left hand piston rings are sound.

Now place the reversing gear in 65 per cent fore-gear, thus opening the right front steam valve, and testing the right front exhaust valve and the right hand piston rings. If one of the exhaust valves is known to be defective from the mid-gear test, it must now be either the right or left hand back valve, so move the engine until the right hand big end is on top *quarter,* and test again in 35 per cent fore-gear. This tests the left hand back exhaust valve, as the left hand big end is now on back centre and the left back steam valve is open to lead steam. If there is no blow in this position, the defective exhaust valve must be the right hand back one, and this can be verified by placing the reversing gear in 65 per cent fore-gear.

If the exhaust valves are known to be in good order from the mid-gear test, but it is suspected that a steam valve is defective, the test should be carried out in a similar manner to the test for individual exhaust valves. Place the right hand big end on bottom quarter, and after applying the brakes, scotching the wheels and shutting off all auxilliary steam, open the regulator with the reversing gear in 35 per cent fore-gear, and open the cylinder cocks. Steam will appear at the left hand front cock, as this steam valve is. open to lead steam. If steam appears at the right hand front cock, the right front steam valve is defective, as it should be shut in this position. If there is a blow up the chimney, either the left hand piston rings or the right hand or left hand back steam valves are defective. To determine which of the valves is blowing, place the right hand big end on *top quarter,* and test in 35 per cent fore-gear. If steam appears at the right back cylinder cock, that steam valve is defective, while if it does not, the left back steam valve must be the one causing the blow. If a blow is heard when the right hand big end is on bottom quarter, and again when it is on top quarter, the left hand piston rings are almost certainly defective, while if no blow is heard in 35 per cent fore-gear, and a blow appears in 65 per cent fore-gear, with the right hand big end on top or bottom quarter, the right hand piston rings should be booked.

If valves are found to be defective, the valve and the seating must be booked for attention. The most common defect found on locomotives, with R.C. valve gear is that one exhaust valve sticks open, on account of a sticky carbon deposit forming on the valve spring. In such a case the valve cover should be given a *light* tap with a hammer, as this will often reseat the valve. The valve should in any case be booked for cleaning on arrival at the depot.

SECTION 11

BREAKDOWNS

Each breakdown to be dealt with on its merits. Action to be taken to avoid breakdowns. Basic purposes of action taken. Action to be taken by drivers. Sending for assistance. Temporary repairs. Broken or cracked wheels & tyres. Broken axles. Broken coupled wheel spring gear. Broken bogie springs & hangers. Broken bissel springs & spring gear. Broken tender spring hangers. Walschaerts valve gear. Broken eccentric crank, eccentric rod or expansion link foot. Broken lifting link or lifting, arm. Broken radius rod. Expansion link broken in the slot or trunnions broken. Broken combination lever, union link or crosshead arm. Broken valve spindle. Roller bearings on motion pins. Steam reversing engine defects. Broken coupling & connecting rods. Broken crossheads & slippers. Broken or bent slide bars. Broken piston rod. Stephenson link. motion. Broken eccentric strap or eccentric rod. Broken reversing rod,, reversing shaft levers, lifting links or expansion link trunnions. Broken swing link. Broken valve spindle inside or outside connecting rod, or broken rocker shaft or arms. Valve spindle or buckle broken inside steam chest (slide valve). R.C. valve gear. Closing steam valves & disconnecting drive. Broken steam valve. Removing connecting rod. Loading of damaged parts. Emergency equipment box. Breakdowns on shunting engines. Haulage of dead engines. Hot bearings. Coupled wheel axle-boxes, grease & oil, bissel & tender boxes. Roller bearing & Isothermos axle-boxes. Coupling & connecting rod bushes, grease & oil. Hot motion pins. Hot slide bars. Hot axle-boxes on coaches & wagons. Emergency water cooling equipment. Broken buffers. Dropped brake gear. Taking numbers of defective vehicles. Serious accidents. Submitting reports.

In this Section the action to be taken by enginemen should breakdowns occur is given as far as it is possible to do so. It must be clearly understood that every case of a breakdown must be dealt with separately and on its merits, and that it is not possible in any handbook to give more than a guide to the methods of dealing with the more common breakdowns. The attention of enginemen is drawn to *Clause 6, Section 1, of the General Appendix (Part 1),* but it must be emphasized that appealing for advice to the Loco Foreman, Running Foreman or other officer some distance away does not help much as a rule, because they *cannot see what has happened.* The enginemen who are on the spot are normally in the best position to judge, and should not be afraid to take what action they think most suitable. An early report to the Loco Foreman or other officer is, however, most desirable so as to avoid delay in arranging for repairs, and to allow of any necessary alterations being made to the engine working roster - see *Clause 45(3), Section IX, of the General Appendix (Part 1).*

Breakdowns are almost always avoidable if all concerned do their jobs properly. As far as enginemen are concerned there are five main things, which if conscientiously done, will avoid a large proportion of the breakdowns which occur. These are:

1. Careful and thorough examination of the whole locomotive and the tender before and after every trip, and additional examination wherever possible along the road.
2. Correct interpretation of anything unusual occurring while the engine is running, and taking the necessary action.
3. Correct and accurate booking of *all* defects. Drivers should always make notes during the journey of any defects found, so as to ensure that these are not overlooked when booking repairs.
4. Proper lubrication.
5. Proper handling of the locomotive and the train.

Many minor defects such as split pins missing, nuts loose or missing, oil cups dirty, and so on, may easily result fairly quickly in a serious breakdown with severe damage to the locomotive, not to mention a great deal of unnecessary hard work, besides the risk of injury to the engine crew.

The basic purposes of any action taken when a breakdown occurs must be:

1. To avoid or reduce delays to other trains and to the traffic on the train which has failed.
2. To prevent further damage being done.
3. To avoid as far as possible the locomotive becoming a total failure and having to be hauled home.

When a breakdown occurs on the road, there are certain things the driver must do before attempting any repairs. These are as follows:

1. Stop the train carefully.
2. Send the fireman to protect the train in terms of *Train Working Regulation No 224.*
3. Examine the engine to see what has actually happened, and think out carefully what should be done, bearing in mind the three basic purposes, of any action to be taken, as mentioned previously. A few minutes lost in deciding what is to be done and how to do it is time well spent.

If assistance is available from another train, a shunting engine or from a running shed, do not hesitate to send for such assistance as quickly as possible, giving the *engine number* and class. This is essential if spare parts are sent from a running shed, as there are sometimes differences between groups of engines of the same class. In busy and congested areas no time should be lost in sending for assistance. The attention of enginemen is directed to *Train Working Regulations Nos 224, 227, 228, 233 & 234.*

In all cases of breakdowns, the broken or damaged parts must be removed or secured in such a way that no further damage can be done, and it must always be remembered that a temporary repair which fails may cause a great deal more damage than the original breakdown. On the other hand no more parts than absolutely necessary should be removed, and as much of the locomotive as possible must be kept working. For example, if it is possible to get some work out of one cylinder where the valve gear has become partially defective, this should be done. Provision must be made for the lubrication of moving parts not removed, particularly pistons and valves. Finally, if assistance is sent for, a start should immediately be made to uncouple any parts which must be removed, so as to save time after the assistance arrives.

WHEELS, TYRES & AXLES

Broken or seriously defective wheels are seldom found, but if such a thing should happen the wheels concerned will usually have to be lifted clear of the rails and carried. This is normally a job for the breakdown gang, but in any case the rods connected to defective coupled wheels on both sides of the engine will have to be removed, so that the enginemen can make a start with this work as soon as the necessary protection has been given and assistance has been sent for. Two or three broken spokes in a wheel need not usually be regarded as dangerous, provided the engine is handled with care.

A cracked or broken tyre should be treated with great care, and if there is any sign that a cracked tyre is tending to work off, the breakdown gang must immediately be sent for. If it is found possible to get the engine clear of the main running line at a station or loop, either by moving it under its own steam or with the assistance of another engine, this should be done. In all cases the driver should examine the defect carefully, and use his discretion as to how far he is prepared to move the engine. The wheels concerned will, in any case, almost certainly have to be carried sooner or later.

If a tyre is found to be loose, it is usually possible with care to get the engine clear of the main running line, and if the tyre is only very slightly loose there is no danger in working the engine and its load to its destination. A pair of wheels with a loose or cracked tyre should never be skidded by locking the wheels with a bar, as the tyre is then bound to rotate on the wheel centre, and will most probably come right off before long. It is sometimes possible to skid wheels with loose tyres by clamping the brake blocks hard against the tyres concerned. If wheels are skidded for any reason it is always desirable whenever possible to run water on the rails just in front of the wheels concerned, and to travel slowly.

In the case of a broken axle it is essential to carry or remove the wheels concerned, and once again this is normally a job for the breakdown gang. The

driver can in many instances do a good deal of any necessary uncoupling before the breakdown gang arrives.

SPRINGS & SPRING GEAR

Broken springs, spring hangers and compensating beams are found from time to time, and in a great many instances do not seriously affect the running of the engine. If the breakage is in the spring rigging of the coupled wheels, the compensating gear will nearly always lock itself before any dangerous movement takes place, so that provided all the moving parts of the engine are clear, it is normally possible for the driver to carry on with caution. If this is not possible, the compensating beams must be packed to isolate the axle-box affected, and it is then often desirable to place some packing between the top of the axle-box concerned and the horn. It is not necessary to pack all the axle-boxes in the same compensating group as the one affected.

In the case of a broken spring or spring hanger on an engine leading bogie, it is usually not possible to carry out any repair work on the road. The bogie should be carefully examined to ensure that the wheels and the bogie frame clear the main frame of the engine, and that nothing is likely to catch on the ground or on the rails when passing over points. If everything is clear, the driver should carry on with care. If the bogie frame or wheels will not clear the main frame, it is necessary to take some weight off the bogie. The easiest way to do this is as follows:

1. Place some hard packing, such as fish plates or buffer nuts between the tops of the axle-boxes of the *second* pair of coupled wheels and the horns, and then run these wheels up on fish plates or wedges. This will lift the front end of the engine, and the leading coupled wheels will drop in their horns.
2. Place packing above the axle-boxes of the leading coupled wheels, filling the gaps between the boxes and the horns.
3. Run the second pair of coupled wheels off the fish plates or wedges, and remove the packing above these boxes.

The leading pair of coupled wheels will then carry more weight than usual, and a good deal of the load on the bogie will be removed.

The driver should then proceed with care, particularly on sharp curves and over points and crossings, and should watch the lubrication of the leading coupled wheel axle-boxes.

Should a bissel spring or spring hanger break, the spring will often jam against the ashpan, and it will then usually be possible to carry on without any further adjustments, except to force some packing between the

ashpan and the firebox foundation ring, where possible, to prevent the ashpan from collapsing. In cases where the spring does not jam, it is normally necessary to take all the weight off the bissel, as weight on one axle-box only will tend to lift the opposite wheel, since the axle-boxes are outside the wheels.

To take the weight off the bissel, the following is the usual procedure:

1. Place packing between the axle-boxes and the horns on the pair of coupled wheels immediately in front of the trailing coupled wheels, and run the packed wheels up on fish plates or something similar, thus lifting the back end of the engine.
2. Fit packing firmly between the trailing axle-boxes and the horns, and then run the next pair of wheels down again, and remove the packing from the axle-boxes of these wheels.
3. Lock the compensation behind the trailing coupled wheels. This may often be done by inserting a coupling pin through the extra hole in the bissel compensating beam and its bracket, or by packing between the bissel compensating beam and the safety strap. This must be done on both sides.
4. Uncouple the bissel side control gear, so that the action of the springs will not tend to derail the bissel wheels, particularly when moving backwards.

A spare tender spring hanger is carried in the emergency kit box on the engine or the tender. If a hanger breaks, the broken parts should be removed, and the end of the spring should be lifted high enough to insert the spare spring hanger by jamming a piece of rail or wood under the spring and moving the engine either forwards or backwards.

WALSCHAERTS VALVE GEAR

A modem Walschaerts valve is shown in **Fig 63**. The normal methods of dealing with the more common breakdowns are as follows:

Broken eccentric crank, eccentric rod or expansion link foot

1. Remove the broken parts.
2. Place the reversing lever in mid-gear, and test this by rocking the expansion link backwards and forwards. If there is no movement at all on the radius rod or the valve spindle, the engine is in true mid-gear.
3. Place wooden blocks tightly in the expansion link above and below the die block, so as to hold it in mid-gear.
4. Uncouple the lifting link from the lifting arm.

The valve concerned will now be moved by the combination lever only, and its travel will be twice lap plus twice lead. A certain amount of assistance will be obtained from this cylinder, but the engine will not start if the opposite crank should stop on either dead centre. To move the engine it is then necessary to remove the lower wooden block and to drop the die block to the bottom of the expansion link, when the valve can be moved by hand as required, and the engine can be shifted to a suitable position for starting.

Broken lifting link or lifting arm

1. Place the reversing lever in about 60 per cent cut-off.
2. Lift up the radius rod until the broken parts meet, and place a block of wood between the die block and the bottom of the expansion link.
3. Place another block of wood above the die block, allowing about one inch play for the slip of the block.
4. Remove the broken parts.

The engine will then run satisfactorily, but it cannot be reversed without changing over the wooden blocks.

Broken radius rod

1. Remove the broken parts.
2. Centralize the valve over the ports. Use marking or steam method.
3. Secure the valve by means of clamps on the spindle, or by canting the glands or by clamping the valve crosshead by means of the screws provided in the valve crosshead guides.
4. Remove inspection caps or cylinder drain cocks.
5. Close the lubrication feed to the valve, and open the feed to the cylinder to give about twice the normal supply of oil.

The engine can then be worked on one side, but should it stop with the good side on dead centre, it is always possible to move the other valve by hand, and thus move the engine. Before moving the valve, the inspection caps must be replaced, and after the engine has been shifted sufficiently, these must be removed again and the valve must be secured.

Expansion link broken in the slot, or trunnions broken

1. Remove the radius rod completely.
2. Centralize and secure the valve, as previously described.
3. If the trunnions are in order, no further uncoupling is necessary, but if they are broken or defective, the expansion link must not be allowed to rock, and therefore the eccentric rod must be taken down by first taking out the link foot pin and then removing the eccentric rod from the eccentric crank.
4. Remove the cylinder cocks or the inspection caps.

5. Close the lubricator feed to the valve and open the feed to the cylinder to give about twice the normal supply of oil.

As in the previous case, the engine can be moved off a dead centre by shifting the valve on the defective side.

Combination lever, union link or crosshead arm broken

1. If the combination lever can be wedged in the vertical position, and if it will clear the gudgeon pin on the crosshead, it is necessary to remove the union link only.
2. Wedge the combination lever in the vertical position, making sure that the valve spindle crosshead is free to move normally.
3. Work the locomotive in about 65 per cent cut-off, as all lap and lead movement for the valve on the damaged side has been lost.
4. If the combination lever will not clear the gudgeon pin, the valve must be centralized and secured. To centralize the valve, place the reversing lever in mid-gear, and pull the combination lever vertical.
5. After securing the valve remove the radius rod completely.
6. Tie the combination lever forward clear of the crosshead.
7. Remove the cylinder cocks or the inspection caps.
8. Provide for lubrication of the piston, as previously described.

If the combination lever is broken, it is sometimes possible to bend it outwards clear of the crosshead, but care must be taken not to damage the valve spindle crosshead or its guides. An undamaged combination lever should never be bent.

Valve spindle broken between the crosshead and the back valve head.

1. Remove the inspection caps.
2. Push the valve back until it is central over the ports, and secure it in front by canting the gland, if there is one, or by fitting a block of wood between the valve head and the steam chest cover.
3. Remove the radius rod completely.
4. Push the valve spindle crosshead forward until the broken parts meet, and secure it, by a clamp or by blocking the crossheads.
5. Remove the inspection caps or the cylinder cocks.
6. Provide for lubrication of the piston as previously described.

On some locomotives certain of the motion pins are fitted with roller bearings. If it is necessary to disconnect any of the rods connected by these pins, the special puller provided in the emergency kit box must be used. Most motion pins with plain bearings are secured by means of two taper pins, and to remove these a sharp blow on the small end is required. Tapping a taper pin with a hammer only bends it or rivets it over so that it becomes almost impossible to remove.

REVERSING GEAR

The steam reversing engine does not often give serious trouble but failure to hold, the reversing gear in the desired cut-off is not uncommon. This is usually caused by insufficient oil in the cataract cylinder, by a leaking cataract valve or by defective leather buckets.

If the reversing gear is found to work right out into full gear the trouble is probably in the cataract valve, and more tension can be given to the spring by placing a washer behind it. If the leather buckets are at fault there is nothing the driver can do on the road, except to lock the motion by placing a block of wood between the buckle and either the oil or the steam cylinder.

If the reversing gear creeps out to some extent and then stops, it is an indication that there is insufficient oil in the cataract cylinder. It is quite easy to fill up the cataract cylinder on the road, and the procedure is as follows:

1. If the cataract valve spindle gland is on the side of the cylinder away from the boiler, which is the usual arrangement, the filling hole runs towards the back of the oil cylinder. Uncouple the rod which moves the cataract valve and see that this valve is in the central position.
2. Give a little steam so that the reversing engine piston rod will move forward, thus compressing the oil in the front end of the cataract cylinder.
3. Remove the filling plug and the vent plug at the back end of the cylinder, and fill up with oil, allowing some space in the oil port for expansion. If no oil is available, water can be used.
4. Replace the plugs and couple up the cataract valve.

If the cataract valve spindle gland is between the oil cylinder and the boiler, as it is on some Garratt locomotives, the filling hole runs towards the front of the oil cylinder. In this case the reversing engine piston rod must be moved backwards before the filling plug and the front vent plug are removed.

As far as the steam cylinder is concerned, the slide valve spindle occasionally breaks. If this should happen, the steam valve on the turret should be cut off. Then put the reversing lever in fore-gear and move the radius rod by hand until the die block is in the position corresponding to about 60 per cent cut-off, and replace the reversing lever in the central position. This will lock the motion by the action of the cataract cylinder. To reverse the engine, opening the steam valve and placing the reversing lever in back-gear will often be sufficient, but if the motion tends to go into fore-gear, the radius rod will have to be lifted by hand.

It sometimes happens that the small copper pipe supplying steam to the reversing engine breaks off at the union nut coupling it to the steam chest. In

this case the union nut should be removed and slipped over the pipe, a small washer should be fitted over the pipe and into the recess in the union nut, and the end of the pipe should be belled out with a punch. The cone which was originally inside the union nut should be removed and the nut should be screwed back into position.

A simple method of locking the motion which can often be used is to place a nut or some other suitable packing between the buckle on the reversing engine piston rod and the block which slides in this buckle. This method is rather risky when the cataract cylinder has failed completely, as the piston rod may be bent. In such a case it is better to place a block between the buckle and either the oil or the steam cylinder, as mentioned previously.

COUPLING & CONNECTING RODS, CROSSHEADS, SLIDE BARS & PISTON RODS

If a coupling rod should break or become bent, it must be removed immediately, and it is absolutely essential that the corresponding rod on the opposite side of the engine be removed at the same time. This applies even if the engine is to be hauled dead. It will in any case usually be found that if a rod breaks the corresponding rod on the opposite side will have bent before the locomotive can be brought to a stop. When the leading coupling rods have to be removed, great care must be taken to make certain that the leading crank pins will clear the crossheads in any position. On some locomotives this is not so, and therefore the leading wheels must be carried, or else the connecting rods must be removed on both sides, the crossheads must be pushed right forward and secured there, and the engine will have to be hauled in.

In the case of a broken connecting rod, the front cylinder cover will almost certainly be broken, and the back cover will most probably be damaged to a greater or lesser extent. The normal method of dealing with this breakdown on an engine with Walschaerts valve gear is as follows:

1. Remove the eccentric rod by knocking out the link foot pin and then slipping the rod off the eccentric crank.
2. Remove the eccentric crank from the driving crank pin by taking out the binding bolt, and then driving a chisel or a wedge into the slot in the eccentric crank, thus loosening it on the square.
3. Remove the broken portion of the connecting rod from the driving crank pin, and take the big end bush out of the eye of the rod and replace it on the crank pin.
4. Replace the eccentric crank.
5. It may very likely not be necessary to remove the portion of the connecting rod still coupled to the crosshead, but if this is essential for safety, the gudgeon pin must be knocked out.

6. Push the crosshead right forward and secure it there.
7. Centralize and secure the valve.
8. Remove the back cylinder cock, and if the front cover is not broken, the front cylinder cock as well.
9. Remove the lifting arm pin to make the good side reversible.
10. Shut off the lubricator to the damaged side.

The engine may then be worked on one side, but care must be taken not to stop with the good side on dead centre.

If a crosshead should break, the front cylinder cover will almost certainly be knocked out, and the back cover will most likely be damaged. The connecting rod will have to be removed, as described in the case of a broken rod, but it must be remembered that the gudgeon pin must be knocked out before the big end can be slipped off the driving crank pin. On many engines it is necessary to place the big end between the bottom front angle and bottom quarter in order to do this, so that it will probably be necessary to centralize and secure the valve before the engine can be set correctly. In any case the cylinder cocks should always be removed before attempting to knock out the gudgeon pin, except that there is no point in taking out the front cock when the front cover is knocked out. The lubricator and the drifting valve must be shut off before doing any of this work, to avoid the possibility of pressure being built up in the steam chest or the cylinder.

Broken crosshead slippers are not common, but if the damage is severe the position should be carefully examined. The directions of thrust on a crosshead while steaming or drifting in fore-gear or in back-gear are given in **Section 5**. From this it will be seen that on the Alligator or Laird types of crosshead if the top slipper is badly damaged it is not possible to steam in fore-gear, while if the bottom slipper is defective it is not possible to steam in back-gear or to drift in fore-gear, and it is undesirable to drift in back-gear. If the engine is travelling forward and the bottom slipper breaks, a temporary wooden slipper should be fitted to the crosshead to prevent it from dropping at each end of the stroke, and a little steam should be kept on all the time the engine is moving. If the breakage is such that the engine cannot be worked on that side, the only alternative is to take down the connecting rod, secure the crosshead right forward and proceed on one side. Before attempting to remove the connecting rod, all steam to front end must be shut off, the cylinder cocks must be removed and the valve must be centralized.

Should the top slide bar or shoe be broken, centralize the valve only. Should the bottom slide bar or shoe be broken, take off the connecting rod.

Broken or badly bent slide bars always involve the removal of the connecting rod, but if the slide bar bolts or studs break it is sometimes possible to clamp the slide bar in position by means of fish plates or a chain.

If a piston rod should break, the front cylinder cover will almost certainly be knocked out, but the back cover is not likely to have been damaged. The action to be taken depends upon how much of the piston rod remains attached to the crosshead, as if there is any risk of this portion striking the back cylinder cover it will be necessary to take down the connecting rod. Removal of the gland and the packing will often help to avoid further uncoupling, but the position must be carefully considered before deciding what is to be done. The valve should, of course, be centralized in any case.

STEPHENSON LINK MOTION

A typical example of a Stephenson link motion is shown in **Fig 68** and the normal methods of dealing with the more common breakdowns are as follows:

Broken Eccentric Strap or Eccentric Rod

1. Remove the eccentric rod and the strap.
2. If it is the fore-gear strap or rod which is damaged, the engine cannot be worked forward on the defective side, so that the valve will have to be centralized. This is done by uncoupling the valve spindle out side connecting rod from the rocker arm, and then moving the valve by hand until steam is cut off from both cylinder cocks. The valve should then be moved about 7/8 inch further, to allow for the lap.
3. Remove the cylinder cocks on the defective side.
4. Provide for lubrication of the piston, and carry on one side.
5. If the back-gear eccentric strap or rod breaks it is usually possible to work the engine in full fore-gear, as the die block is then directly opposite the eccentric rod pin. The bottom of the expansion link should be tied up to the brake gear to prevent it from flapping about.

Broken Reversing Rod, Reversing Shaft Levers, Lifting Links or Expansion Link Trunnions

1. Either the whole motion, or that on one side will drop into full fore-gear.
2. Place the reversing lever in about 60 per cent cut-off, and lift up the motion until the broken parts meet.
3. Fit a block of wood between the die block and the top of the expansion link on one side, and another block below the die block, allowing about one inch for the slip of the die block.
4. Keep the regulator slightly open when drifting, as the motion cannot be put into full gear. The engine cannot be reversed without changing over the wooden blocks.

On some locomotives, if the reversing rod or the vertical arm on the reversing shaft breaks, it is possible to lock the motion in the desired cut-off by fitting packing between the vertical arm and the slot in the running board through which it projects.

Broken Swing Link

1. The die block will drop to the bottom of the link. Place the reversing lever in about 60 per cent cut-off, and lift the valve spindle inside connecting rod until the broken parts meet.
2. Fit a block of wood between the bottom of the expansion link and the die block, with a loose block above the die block.
3. Keep the regulator slightly open while drifting.

The engine cannot be reversed without changing over the wooden blocks.

Broken Valve Spindle Inside or Outside Connecting Rod, or Broken Rocker Shaft or Arms

1. Remove the broken parts.
2. Centralize and secure the valve, by marking or steam method.
3. Remove the cylinder cocks.
4. Provide for lubrication of the piston, and proceed on one side.

Valve Spindle or Buckle Broken Inside the Steam Chest (Slide Valve)

1. Examine motion to see that no pins have been lost.
2. Remove the snifter Valve in front of the steam chest and push the valve back until it is central over the ports, and fit a block of wood between the valve and the steam chest cover to hold it there. Replace the snifter valve.
3. Take off the outside rocker arm pin, and push the back portion of the spindle forward until the broken parts meet, and secure the spindle in that position.
4. Remove the cylinder cocks.
5. Provide for lubrication of the piston, and proceed on one side.

R.C. VALVE GEAR

The fundamental difference between this gear and the Walschaerts or the Stephenson valve gear is that there are four separate valves to each cylinder instead of only one, and therefore it is not possible to 'centralize the valve'. It is, however, quite easy to close both steam valves on one side, and so prevent steam from acting on that piston. The normal method of doing this is as follows:

1. Place the big end between either dead centre and one of the angles and put the reversing gear in 85 per cent cut-off.

2. Disconnect the tubular driving shaft at the flanged joint next to the gear box on the return crank, and tie the end of the shaft to the anchor link or some other suitable part clear of the gearbox.
3. Disconnect the flanged coupling on the reversing shaft in front of the cross shaft gear box (‘mitre box').
4. Remove the cylinder cocks.
5. Shut off the lubricator feed to the steam chest, and proceed on one side.

Any defect in the valve gear which prevents the valves working properly, or a broken exhaust valve would be dealt with in this manner. If it is impossible to set the engine with the big end in the position indicated, the tubular driving shaft should be turned by hand after disconnecting, until no steam appears out of either cylinder cock.

In the case of a broken or seized steam valve, the following procedure should be followed:

1. Place the reversing gear in mid-gear, thus opening the steam valves and closing the exhaust valves.
2. Disconnect the flanged coupling on the reversing shaft in front of the cross shaft gear box on the defective side, thus holding this side in mid-gear.
3. Proceed on one side, floating the other piston in steam.
4. Do not remove the cylinder cocks.

REMOVING CONNECTING RODS

If it is necessary for any reason to take down a connecting rod, the following method should be adopted:

1. Close both steam valves on that side, as described previously.
2. Uncouple the anchor link on the return crank gear box.
3. Remove the return crank with the gear box still on it, and avoid spilling the oil out of the gear box.
4. Remove the connecting rod, as described earlier, and replace the big end bush on the driving crank pin to hold the coupling rod in position.
5. Replace the return crank with the gear box, and couple up the anchor link.
6. Push the crosshead right forward and secure it there.
7. Remove the back cylinder cock, and if the front cylinder cover is not broken, remove the front cock as well.

GENERAL

Damaged or broken parts removed from locomotives should always be loaded and secured on the engine unless they are too heavy to lift. It is sometimes

possible, if assistance is available from gangers or other servants, to load heavy parts into a truck on the train, but if this is done care must be taken to ensure that these parts are offloaded at the depot station. When it is impossible to load up heavy parts on the engine or the train concerned, a note must be taken of exactly where the parts are lying (e.g. 'between mileages 517½ & 517¾ near the culvert') and the operator at the first station and the ganger must be advised so that the parts can be picked up and despatched to the loco depot as quickly as possible. In addition to any written report submitted, it is always desirable for a driver to make a personal report to the Locomotive Foreman as soon as he can after arriving at the shed.

All engines except those used regularly for shunting carry an emergency equipment box which is sealed. The standard contents of this box are given in *Clause 51(2) Section IX, of the General Appendix (Part 1),* and these are sufficient for dealing with most breakdowns.

Should a breakdown occur on a shunting engine, assistance must be sent for immediately, while the driver does any necessary uncoupling as far as he is able. Attempting to carry out temporary repairs, except minor ones, is almost always a waste of time in a shunting yard.

When it is necessary to haul an engine dead, the provisions of *Clauses 17 & 17A of Section I of the General Appendix (Part 1)* must be observed.

HOT AXLE-BOXES & OTHER BEARINGS

If any bearing runs hot on a locomotive, the first thing to do is to find out the cause of the heating, and then, if at all possible, to remove this cause. In nearly all instances heating are caused by lack of lubrication, and this can often be remedied quite easily if action is taken quickly.

Heatings of coupled wheel axle-boxes are frequently caused by lack of lubrication of the boss face, so that this is a point which requires close attention. Another common cause of heatings on grease lubricated axle-boxes is that the grease pad sticks clear of the journal so that no lubricant is fed to it. If the grease pad can be freed so that the perforated plate is touching the journal, the box will usually cool off again. If the grease pad has melted out completely, some more grease must be supplied. Three or four sticks of grease for use in the hard grease gun placed between the perforated plate and the journal have been known to supply sufficient lubrication to run the axle-box for a long distance. In all cases of hot coupled wheel boxes, the wedges should be slackened off, as the boxes expand considerably when hot. In emergencies it is sometimes possible to run coupled wheel axle-boxes on cylinder oil or even on water, but in such cases the axle-box must be allowed to cool off somewhat before applying the oil or the water. It sometimes helps to take

some weight off the wheel concerned by running the wheel up on a fish plate and inserting packing between the spring saddle and the frame on an engine with overhung springs, or between the hornstay and the keep on an engine with underhung springs.

When oil lubricated axle-boxes run hot, and if the white metal has not been melted out, the trimmings should be renewed and the axle-box should be oiled freely. If it is possible to get at the waste packing, this should be teased out and oiled, making certain that it touches the journal along the full length when replaced. A little cylinder oil poured directly into the syphon pipe will often help to cool down an axle-box, but care must be taken not to allow the trimmings to soak up cylinder oil, as they will then become choked. If the white metal has melted, the pieces should be removed, and grease should be forced in between the waste packing and the journal.

If bissel or tender axle-boxes fitted with plain bearings run hot, the packing should be removed, teased and properly replaced, and the box should be filled up with oil. If this does not cure the trouble, no time should be lost in fitting a water connection to the axle-box and running the box on water.

Overheating of roller bearing axle-boxes is not common, but when such an axle-box becomes too hot for the hand to be held against it comfortably, it is a definite sign that something is seriously wrong inside. The only thing the driver can do is to carry on slowly until he can stable his load clear of the running line, and then communicate with the loco depot for instructions. The same applies to Isothermos axle-boxes.

If grease lubricated coupling or connecting rod bushes run hot, the driver must supply grease to the bearing as often as necessary, and should work the engine in as long a cut-off as practicable so as to give a more even force on the crank pins. With oil lubricated bushes, cylinder oil poured directly into the syphon pipe will often help considerably provided the oil way has not become blocked up. To clear the oil way it is usually necessary to remove the rod from the crank pin, which is always a rather lengthy job. If the white metal has melted, it is often possible to force grease into the bearing through the set screw hole at the bottom of the eye of the rod.

HOT MOTION PINS & SLIDE BARS

A hot motion pin should be treated by ailing freely with cylinder oil, and by renewing the trimming. If this does not help, it will often pay to knock out the taper pins and thus allow the pin to turn in the fork end as much as is necessary, and to oil it frequently by hand. If the motion pins are lubricated with soft grease, frequent use of the grease gun will often assist. Turn oil swab around pin so that pin will not work out.

Hot slide bars are often caused by lack of proper lubrication or by dust, and oiling freely will in many instances cure the trouble. Spreading some soft grease along the bars also helps, but it must be remembered that this grease will not stay on the bars for long, as the crosshead will wipe it off.

The heating may be caused by the slide, bars being too tight and if this should occur the bars should be separated a little by inserting, or removing liners, depending upon how the bars are fitted. This cannot, however, be done with the Laird type of crosshead.

HOT AXLE-BOXES ON COACHES & WAGONS

Hot axle-boxes on coaches and wagons should be treated by removing and teasing the waste packing, and oiling it thoroughly. If the packing has been charred or burnt it must be removed, and to replace it a little packing should be taken out of each of the other axle-boxes of the truck concerned. Waste should not be taken from other vehicles unless it is unavoidable, and then these vehicles must be labelled for attention. Dining cars carry emergency water cooling equipment for use on passenger vehicles, and full instructions for its use are given in *Clause 121, Section IX of the General Appendix, (Part 1).* Vehicles which develop hot axle-boxes should in most cases be detached at the first convenient point, but in any event the driver has the final say as to what is to be done. The attention of enginemen is drawn to *Train Working Regulation No 115(2)* and to *Clause 44, Section II and Clauses 122 & 123, Section IX of the General Appendix (Part 1).*

BROKEN BUFFERS

Broken or pulled out buffers should be dealt with as follows:

1. If at all possible, replace the broken or pulled out buffer in the headstock of the vehicle concerned, to take any buffing forces.
2. Couple it to the buffer on the next vehicle by means of a link and pins.
3. Fit the emergency coupling carried on the engine, to the brackets provided immediately below the buffers of the vehicles concerned, and screw up the nuts so as to give as little play as possible.
4. Handle the train with great care, and examine the defective vehicle as often as practicable.

DROPPED BRAKE GEAR

Dropped or uncoupled brake gear on a vehicle is a matter which should receive immediate attention, as otherwise a derailment is likely to occur. The loose parts should be removed or be properly secured, and the vacuum cylinder concerned must be disconnected and a through pipe must be made. The vehicle must be labelled for attention. Enginemen should always take the

numbers of any vehicle known to be, or suspected of being defective, whether these vehicles are detached or not, so that the carriage and wagon staff may be advised, and these numbers should be quoted in any reports submitted.

SERIOUS ACCIDENTS

Ambulance boxes and wrecking equipment boxes are carried on all dining cars and all main line passenger vans, and no time should be lost in obtaining and using the equipment should the necessity arise. See *Clause 35, Section IX of the General Appendix (Part 1).*

Instructions as to the action to be taken when a serious accident occurs are given in considerable detail in *Section X of the General Appendix (Part 1)* and the attention of enginemen is directed particularly to *Clauses 1, 5, 6, 12, 17, 21, 23 & 25* of this Section. Other Clauses in this Section which enginemen should remember are *32* and *35*.

In all reports, whether verbal or written, accurate and complete information must always be given. The time at which an accident occurred is most important, and should always be noted. When written reports are submitted, it must never be assumed that the person dealing with the report later will know all about the incident, so that the full story must be told. It is always desirable to prepare a report as soon as possible after the incident, while everything is fresh in the mind.

SECTION 12

HANDLING OF LOCOMOTIVES & TRAINS

Bunching & jerking avoidable. Safety & sobriety. Signing on duty. Examination of engine & tender before trip, booking of repairs. Preparation of engine. Examination of engine & tender after trip, booking of repairs. Testing for knocks. Entering traffic yard. Coupling to train. Examination of couplings. Creating vacuum. Consulting the guard. Warming up cylinders. Use of cylinder cocks. Starting the train. Skill required to handle goods trains. Testing train brakes. Wide open regulator & short cut-off essential for economical working. Control of slipping. Running at an even speed. Making up time. Correct method of shutting off steam to drift. Use of drifting valve. Keeping train stretched. Working of brake through dips & over rises and changing grades. Steaming against the brake. Correct way to work the brake. Examples of working brake over changing grades. Working of brake on long falling grades. Vacuum stop alarm. Stopping of trains. Use of large ejector. Running through stations, etc. Maximum permissible speeds. Emergency calls at token stations. Keeping a sharp lookout at all times. Use of engine whistle. Animals on the line. Frightening of animals. Shunting. Knowledge of regulations & instructions, keeping up-to-date and teaching firemen. Discipline & cleanliness on the footplate. Co-operation with other servants. Submitting reports. Methods of handling regulator when starting trains. Opening regulator after drifting. Pooling of locomotives. Looking after locomotives & jobs. Signs of a good driver. Pride in the job.

The art of handling a locomotive so that the train behind it runs smoothly and steadily, without bunching or jerking, is one which requires careful study and above all continuous vigilance and attention to the job. There is ample proof that jerking and severe bunching of trains is definitely avoidable, and while correct marshalling and proper adjustment of the brakes play an important part, a great measure of responsibility rests on the driver. A number of useful hints on the handling of locomotives and trains are given in this Section, together with instructions concerning examination and preparation of engines, and the treatment they should receive.

The most important consideration of enginemen and other staff must always be SAFETY, and in this connection *Train Working Regulations Nos 3 & 10 and page vi* (opposite Page 1) *of the General Appendix (Part 1)* should be studied and remembered at all times. Sobriety and general fitness are also of the greatest importance, and all enginemen should do their best to keep up the excellent reputation for steadiness and reliability which has been established throughout the history of these Railways. (See *Train Working Regulation No 8*).

After signing on duty, enginemen must read carefully all the notices posted up for their information, and must obtain and sign for any notices issued to them. The engine must then be thoroughly examined and properly prepared for the trip. Detailed instructions for the filling and starting of the hydrostatic lubricator, and concerning the various types of trimming used are given in **Section 6** (Lubrication). Instructions concerning the examination of the boiler and boiler mounts, and the preparation of the fire are given in detail in **Section 9** (Management of Boilers).

The first duty of the driver and the fireman after arrival at the locomotive is to examine the boiler, test the water gauges, injectors, ashpan cooler, grates and ashpan slides, as detailed in **Section 9**. On his way to the smokebox, the driver should examine one side of the engine, looking particularly for loose bolts and nuts, missing split pins or cotters, and all other parts likely to affect the running of the engine. The clearance of the bogie wheels and frame from the main frame must always be checked, and the cowcatcher bolts and stays must be examined. It is important to test all bolts, nuts and taper pins by tapping them with a light hammer, as if this is done conscientiously, a great many breakdowns and failures will be avoided, and much serious and expensive damage will be prevented. The sand gear must be tested to see that it is working properly on both sides.

After examining the smokebox as described in **Section 9**, the driver should examine the other side of the locomotive, and then should examine the tender right round, so that he comes back to the point from which he started. A systematic examination right round the engine and the tender is of great value, and the eye soon becomes trained to spot defects. If any defects are found they must be reported immediately for attention, and must also be entered in the repair book, as otherwise the driver will almost certainly be held responsible should any delay result during the trip.

When the outside of the engine has been examined, the driver must examine the locomotive and the tender underneath, unless examination pits are not provided. Particular attention must be paid to the bogie swing links and side control gear, brake rigging, ashpan slides, and intermediate drawgear. It is always essential for safety for the driver to tell the fireman before he goes underneath the engine, and to ensure that...

- the regulator is closed;
- the reversing lever is in mid-gear;
- the cylinder cocks are open;
- the brakes are applied.

While the driver is examining the engine, the fireman should be preparing the fire, and fill the lubricator, as described in **Section 6**. The lubricator must be started at least fifteen minutes before the engine leaves the running shed.

As soon as the examination of the engine has been completed and arrangements have been made for any necessary repairs, the driver should attend to the lubrication of the engine. If the fireman has satisfactorily completed his other duties, there is no reason why he should not assist the driver in greasing and oiling, but when this is done the fireman must work under the driver's direct supervision, and not on the opposite side of the locomotive. The driver will at all times be held solely responsible.

The best position to set an engine for greasing and oiling is with the big end on the side concerned on back centre. When the lubrication on that side is completed, the engine should be moved until the other side is on back centre. All grease nipples must be wiped clean before applying the grease gun, and oil cups should be filled up to not more than about ½ inch from the top of the syphon pipe. It almost always pays to pour a few drops of oil directly down the syphon pipe before replacing the trimming, as this gives the bearing surfaces concerned a good start. Trimmings must be clean and of the correct size and type. (See **Section 6**.)

While lubricating the engine there is a further chance to make sure that everything is in order, but the main examination should be done before lubricating. This gives a better chance for any necessary repairs to be carried out without causing delay, and further the driver is doing one thing at a time.

Before leaving the running shed, the driver should satisfy himself that everything is in order for the trip, and that the tender contains sufficient coal and water. He should also see that no tools or loose parts are left on the engine where they might fall off. Finally he must set the small ejector to give as high a vacuum as possible, and must test the vacuum and steam brakes - see **Section 7**. The attention of enginemen is drawn to *Train Working Regulations Nos 159, 160, 161, 162 & 163.*

After completion of a trip, the procedure for examination is similar to that before starting. Any defects noticed along the road should be written down in a note book, so that they, together with any other defects seen during the examination, may be entered in the repair book correctly. Trusting to the memory when booking repairs will sooner or later result in trouble. All the wheel tyres must be examined and be tapped with a hammer. Regarding lubrication, it is most important to withdraw all tail trimmings except those on axle-boxes, as mentioned in **Section 6**. The hydrostatic lubricator must be shut off fifteen minutes before stabling the engine.

The accurate booking of all defects is of the greatest importance, and this is not possible without thorough examination. At some centres, facilities for underneath examination by enginemen do not exist, and arrangements are then made for the shed staff to do this. It is necessary, however, for the driver

to book 'Underneath to examine'. The attention of enginemen is directed to *Train Working Regulation No 161* and to *Clauses 42, 45(4), 45(5) & 63(1), Section IX of the General Appendix (Part 1).*

The best position to set an engine to test for knocks is with the big end on the side concerned on top quarter. If the brakes are fully applied, and the regulator is slightly opened while the engine is reversed from fore-gear to back-gear, the extent of the knocks in the small end, crosshead slippers, big end and driving axle-box can easily be seen. For testing the coupling rod and knuckle joint bushes, the simplest and most effective method is to lift the rods in turn with a bar, when it is easy to see how much play exists. It is essential to ensure that there is no steam pressure in the cylinders when carrying out this test, as otherwise the rods will be pulled up tight against the crank pins.

Before entering the traffic yard from the loco, the driver must give the necessary whistle signal, as laid down in the *Local Appendix*, or must use the telephone where one is provided for this purpose. The necessary fixed signal or hand signal to enter the traffic yard must be clearly seen, or verbal instructions received, before the locomotive may be taken past the limit of the loco yard. The engine must be moved slowly, and it is essential that both the driver and the fireman keep a sharp lookout, as the engine may be entering an occupied road, and in any case the movement is, in effect, a shunting movement. See *Train Working Regulation No 173(6).*

When coupling up to the train, the engine must be handled with care, and no more than a firm squeeze is necessary to allow automatic couplers to engage and lock properly. Unless some other qualified servant is available for the purpose, the fireman must couple up all connections between the locomotive and the train - see *Train Working Regulation No 167(1).* When a link and pins are used, it is absolutely essential to use a link lifter - see *Train Working Regulation No 125(1)* and also to use the correct type of pin. An automatic coupler must have the flat headed pin, usually called a 'patent pin', and a bell buffer must have the pin with the raised triangular head. When coupling an automatic coupler to a bell buffer it is almost always better to place the link in the automatic coupler first, and then slip it into the bell buffer.

After the engine has been coupled to the train, the driver must see that the coupling is secure. When two automatic couplers are concerned, the knuckles must fit together reasonably well, as, if there is any great difference in buffer height, they may slip out of engagement. See *Train Working Regulation No 167(2).* He must then immediately create vacuum throughout the train, using the large ejector to assist the small ejector up to 15 inches, and as soon as he is satisfied that the small ejector alone will maintain at least 15 inches, he must apply the brakes fully, and again create vacuum, using the large ejector if time is limited. The procedure is fully described in **Section 7**. The attention

of enginemen is directed to *Clause 19(5), Section 1 of the General Appendix (Part 1),* where instructions are given concerning the working of trains with a lower degree of vacuum than 15 inches. It is most important in such circumstances to ensure that no leaks can be found on the train, and that the ejector is working properly.

Before leaving, the driver must obtain from the guard as much information as possible concerning the work to be performed on the trip and the tonnage of and the number of axles on the train. The driver should also compare his watch with that of the guard and should check up on the issue of any special notices or instructions which may have been missed or not yet received at the running shed when he signed on duty. The guard should also advise the driver if any trucks containing dangerous goods are on the train. See *Train Working Regulations Nos 181 & 185 and Clause 44(5), Section II of the General Appendix (Part 1).*

The right away signal must be given by the guard, so that the driver is able to be certain that the correct degree of vacuum is registered on the van gauge.

The cylinders should be warmed up as far as possible before the train leaves, and the best way of doing this is to open the cylinder cocks and just crack the regulator, with the reversing lever in mid-gear. With this method the steam is passing through the superheater elements, and is thus as hot as it is possible to get it, and a high degree of superheat will be obtained almost immediately the train starts. Care must be taken to avoid the steam chest pressure rising higher than just a few pounds per square inch, as otherwise the engine may move. The cylinder cocks should be kept open long enough after the train has started to ensure that no water is left in the cylinders, and should be closed as soon as it is safe to do so. Water is best drained from the cylinders while standing with the regulator closed or almost closed as, if steam at any substantial pressure is present in the cylinders, it may blow a hole through the water and so escape without removing the water.

Great care must be taken when starting a train to avoid jerking and possibly breaking a buffer. Trains made up in a yard are nearly always bunched to some extent, so that the load must be picked up gently, and the train must not be accelerated until it is certain that all the slack has been taken up. On the journey the train should always be stopped so that the couplings are tight, and if this is done starting without a jerk is quite easy. It is most important before starting to ensure that the brakes are fully released throughout the train, as otherwise jerking is almost certain to occur. If a train is stopped for any reason on a rising gradient, it is always desirable to open the sand just before the engine comes to a stand, so that the sand is spread along the rails under all the coupled wheels. This makes starting without slipping much

easier. As soon as the engine stops, the sand must be shut off, and must not be opened again until the train is started.

When two locomotives are used on a train, extra care is necessary to avoid jerking when starting and when stopping - see *Train Working Regulation No 170, Clause 19(15), Section I and Clauses 43(7) & 43(8), Section II of the General Appendix (Part 1).*

There is no reason whatever for handling a goods train with less care than a passenger train, and in fact more skill is required to avoid serious jerking and bunching on a goods train than is necessary with most passenger trains. It must be remembered that severe damage can easily be caused to trucks and to their contents, which often involves the Administration in heavy financial loss, and that many bad derailments have occurred through bunching and jerking which can be avoided with the exercise of proper care.

As soon as possible after starting on the journey, the train brakes should be tested in terms of *Clause 19 (10), Section I of the General Appendix (Part 1).* A satisfactory test is possible only on a falling gradient so that on some sections it is necessary to run for several miles before any real test can be made. In any event the brakes must never be relied upon for a rapid stop until they have been tested, and therefore it is essential to approach signals and to enter stations with great caution until such time as it is possible to test the brakes.

When steaming, the cut-off should be as short as possible, and the regulator should be as wide open as circumstances will permit. (See **Section 5**.) It will be found that most modern locomotives can be worked at quite short cut-offs, and it must be remembered that the shorter the cut-off the more economically is the steam being used, and therefore the less is the consumption of coal and water. If the cut-off is too short for the load and the speed, it will be found that knocking starts in the driving axle-boxes and the connecting rods. Drivers should use the reversing lever almost as much as the regulator for controlling the power output of the locomotive, and while locomotives of different classes (and even in the same class) vary considerably in their response to varying cut-off, it does not take a competent driver more than a few miles to get the best out of any engine.

At low speeds no attempt should be made to run at short cut-off as this encourages slipping. After starting, the cut-off should be progressively shortened and the regulator should be opened more and more, but if slipping should occur on a heavy gradient the regulator should be eased and the cut-off lengthened to give a more even turning effort. Slipping is liable to cause severe damage and is almost always a sign of bad driving. It can be largely avoided by light sanding of the rails, particularly when starting and when entering a curve on a heavy gradient. Sand must *never* be used while the

locomotive is slipping violently, as this will cause severe shocks to the rods and axles, and may easily result in serious damage. It is essential to check any slipping which may occur before the sand is opened. Locomotives are always liable to slip while steaming over points, particularly when entering or leaving loops or sidings, and in such places it is better to handle the engine with care rather than to use sand to avoid slipping. Sand should not be used when passing over points if it can possibly be helped.

It is sometimes found that the sand on the right hand side of the engine works much better than on the left hand side. This is usually due to lost motion in the rods and levers connected to the left hand sand valve, so that it is sometimes necessary to open this valve by hand. To avoid undue stresses being set up in the coupled wheel axles, it is most desirable that the sand should work equally well on both sides of the engine, and drivers should book any defects in this connection.

After the train has been started, it should be accelerated as rapidly as possible, without allowing the locomotive to slip, up to the normal speed for the section. Once this speed has been reached, it should be held as constant as possible, while allowing for any speed restrictions, either permanent or temporary - see *Train Working Regulations Nos 176 & 177*. Running at a reasonably even speed is the easiest way to keep time, and also gives the train a steady run with the least chance of jerking or bunching. It is always desirable, whenever it is required to reduce speed for a curve, to do the necessary slowing down before the engine enters the curve, and then to allow the train to accelerate very slightly as it passes round the curve. Care must be taken, however, to see that the rear end of the train does not run too fast round the curve.

A steady speed over rising and falling gradients is in practice the most economical way of handling a locomotive. This principle should be borne in mind when making up time - see *Train Working Regulation No 176(3)*, but it must be remembered that it is always safer to run faster than usual on a rising gradient than it is on a falling gradient. The reasons for this are (1) that it is much easier to slow down or stop quickly on a rising gradient, and (2) that a train runs better on straight track and on curves when it is being pulled hard on a rising gradient. It therefore follows that time should be made up as far as possible on rising gradients, rather than by running excessively fast on falling gradients, where the driver is compelled to rely entirely on the brakes to control the train. Drivers should always make up lost time on both passenger and goods trains whenever it is possible to do so with safety. In addition, in the case of goods trains, drivers should, within the permissible speeds laid down, gain time when the load permits. In the end it is to the advantage of all concerned if traffic can be moved quickly, provided risks are not taken in so doing.

When shutting off to drift, there is only one correct method of handling the various controls on any locomotive, and it is absolutely essential that drivers should always shut off correctly so as to avoid serious deposits of carbon forming in the steam chests, the cylinders and the blast pipe. The correct method of shutting off is as follows:

1. Open the drifting valve, if one is provided.
2. Ease the regulator, but do *not* close it.
3. Drop the reversing lever out into full gear.
4. Close the regulator.

This applies on all locomotives except those fitted with R.C. valve gear. With this gear the correct method of shutting off is as follows:

1. Ease the regulator, but do *not* close it.
2. Place the reversing gear in mid-gear.
3. Close the regulator.

Where drifting valves are provided they *must* be used. The Administration takes a very serious view of the failure of drivers to use drifting valves. Where drifting valves are not provided, the regulator must be left very slightly open to supply a little steam to the cylinders, The action of the steam admitted to the cylinders from the drifting valve is described in **Section 5**, and the advantages gained have been proved by many practical tests. It must be emphasized that a driver who does not use the drifting valve because he considers, it of only theoretical advantage shows serious ignorance of his job.

The drifting valve must be closed shortly before the train is brought to a stand, as otherwise sufficient pressure may be built up in the cylinders to move the train.

Throughout the journey, from the start to the final stop, the train must be kept stretched. This is not difficult, even when running through dips and over changing grades, provided the proper technique is used. While the train is moving, it will be kept stretched as long as the regulator is sufficiently wide open and the locomotive is pulling, but as soon as the regulator is closed, the driver has the brakes alone to keep the train stretched and to prevent bunching until such time as the locomotive again starts to pull. The driver must therefore, in effect, see that he so handles the brakes that they will hand the train back to the control of the regulator in a fully stretched condition.

Bunching and jerking occur when the rear portion of the train starts to run faster or slower than the front portion, a situation which is certain to arise when running over changing grades, unless steps are taken to prevent it. If the regulator is open, and the locomotive is accelerating the whole train, the rear portion is not likely to catch up on the front portion and cause a bunch

with a subsequent jerk. In many places where there are awkward dips or rises it is not possible to accelerate the train sufficiently to keep it stretched. This applies particularly to goods trains limited to 35 miles per hour or less, and where the load is often too heavy to allow of the necessary acceleration.

In such circumstances, the brakes must be used to keep the train stretched, and it is here that the 'delayed action' of the vacuum brake proves extremely useful. As pointed out in **Section 7**, the brakes are applied and released sooner near the front of the train than near the rear. When running through a dip it is possible to have the brakes near the front of the train just coming off as the engine reaches the bottom of the dip, while the brakes on the van remain applied lightly until it also reaches the bottom, thus preventing the rear portion of the train from catching up the front portion and causing a severe bunch. Similarly when coming over a rise, the brakes can be applied near the front of the train thus preventing it from accelerating rapidly and causing a jerk on the slower moving rear portion.

When running over a series of up and down grades it almost always pays to keep the brakes slightly applied to the extent of two or three inches, and varying this by about one or two inches at a time to suit the changing gradients. In some places the train will not run by itself over such up and down grades, so that it is necessary to use the regulator, but even so, unless the train can be rapidly accelerated, the brakes must be used to keep it properly stretched. There is no objection whatever to making a slight brake application while the engine is steaming lightly. The waste of power is negligible compared with the damage to vehicles and to their contents which can be prevented by correct use of the brakes.

The correct way to apply the brake is to reduce the vacuum in the train pipe by two or three inches only, in sufficient time for the brakes to take effect where they are wanted. The application valve handle should be held as steadily as possible, and should be moved slowly up or down to ease the brakes or apply them a little harder as circumstances demand. A rapid up and down movement of the application valve handle, or 'seesawing' as it is sometimes called, is extremely bad practice, and must never be allowed. While many drivers handle trains reasonably successfully by using other methods of working the brakes than that described, it has been found on extensive practical tests that a steady application, to the extent of only two or three inches at a time, is most effective in avoiding jerking and bunching, and further it gives the driver excellent control over the train. Once the brake has been applied throughout the train by reduction of two or three inches in the vacuum, a full application can be made in an emergency with little or no danger or bunching the train or of causing damage.

Drivers must, of course, have a thorough knowledge of the roads over which they work trains, and if a study is made of the places where bunching and jerking are likely to take place, it will be found that by using the methods described, the trouble will be greatly reduced and in many cases entirely eliminated.

Two diagrams of typical sections of track are given in **Fig 101** and on the diagrams the amount of brake to be applied and the places to open or shut the regulator are indicated as a guide to drivers. These apply to average conditions of train weight and length, and to normal brakes, so that they will require some variation to allow for different conditions. The general principles, however, remain the same, and should be applied to get proper results. The large ejector should not be used for releasing the brakes while running, except where it is necessary to recreate full vacuum rapidly.

When descending long steep gradients, it is absolutely essential for the driver to be certain that he has proper brake power available all the way. As a certain amount of internal leakage goes on all the time, the brakes will leak off sooner or later, unless the air which has leaked into the spaces above the pistons and into the vacuum chambers is withdrawn by creating full vacuum from time to time. The best method of recreating full vacuum while descending a long gradient is to check the train by a fairly heavy brake application just before reaching a sharp curve, and then to use the large ejector to assist the small ejector as the engine enters the curve. Curves, particularly if fitted with check rails, cause a considerable drag on the train, so that speed will not increase rapidly while vacuum is being recreated on a curve. Further, the actual gradient on a curve is usually reduced or 'compensated' so as to make it easier for trains to run up the bank, and therefore there is less tendency for a train to run away on the down gradient while it is on a curve.

Drivers of passenger trains must always be alert for a light brake application caused by the vacuum stop alarm in main line saloons. See *Clause 19(30), Section I of the General Appendix (Part 1)* and **Section 7** of this Handbook.

When stopping a train it is most important to get all the brake blocks throughout the train in contact with the wheels before attempting to apply the brakes at all hard. This can be done by reducing the vacuum by 2 or 3 inches in good time. After sufficient time has been allowed for the brakes to take effect on all the vehicles, the vacuum should be further reduced, from 5 to 10 inches usually being quite sufficient, until it can be seen that the train will stop where desired. The application handle should be placed in the running position before the train stops so as to allow the small ejector to release the brakes slowly and prevent a sudden jerk. As the brakes will release sooner on the front portion of a train than on the rear portion, the

train will be kept stretched, and a start without jerking is then quite easy. The vacuum on the engine should if at all possible be almost fully recreated by the time the train actually comes to a stand. The large elector should not be used until the train has come quite or almost to a stop, and then only when the time available to recreate vacuum is short. If the large ejector is used after a fairly heavy brake application, and while the tram is still moving at a fair speed, the brakes will be released so rapidly near the front of the train that a jerk is almost inevitable, and further the engine will run back against the train as soon as it stops, which may compress several buffers thus making a smooth start difficult. Use of the large ejector when stopping a long goods train often causes damage and may easily result in a broken buffer near the rear of the train. The attention of enginemen is drawn to *Clause 19(1), Section I of the General Appendix (Part 1).*

When running through stations, interloops, sidings, etc., the maximum speed permitted over facing and trailing points, as laid down in *Clause 11, Section I of the General Appendix (Part 1)* must not be exceeded, and the attention of enginemen is also directed to *Train Working Regulation No 177.* Particular attention must be paid to the speed of the train when leaving a loop line, as it is easy to pick up speed sufficiently rapidly for the rear end to run over the trailing points a good deal faster than is either comfortable or safe. The speed restrictions mentioned in the *General Appendix* and local appendices apply to the whole train, not merely to the locomotive.

When running through or standing at token stations, trainmen must be on the alert for the station code ring or the emergency call (4 long rings) on the telephone, and must promptly respond. See *Clause 20(5), Section V of the General Appendix (Part 1).*

The most important duty of enginemen is to keep a sharp lookout at all times, and to avoid accidents by taking action in good time. It can safely be said that most collisions which have occurred could have been avoided if the enginemen were fully on the alert, and drivers must see that their firemen are trained to keep a proper lookout whenever possible, and particularly when approaching and passing stations, halts, loops, sidings, signal cabins and level crossings, and while running around left hand curves. (See *Train Working Regulation No 171*). Particular attention must be given when running permissively behind another train, and the danger signal which may be exhibited by the guard of the train ahead must be obeyed immediately. The detonators put down by the guard who is protecting his train are the last line of defence, while the danger hand signal can normally be seen from a considerable distance if it is properly exhibited. A sharp lookout must be kept to avoid striking gangers' trolleys: such accidents occur much too frequently.

The engine whistle must be used as laid down in *Train Working Regulation No 172*, and in *Clause 18, Section I of the General Appendix (Part 1)*. The greatest care must be taken to avoid running into animals which may be on the line, as several serious derailments have been caused in this way, apart from heavy expenditure in claims in which the Administration is often involved. The loss of a few minutes in slowing down or stopping to avoid animals is handsomely worth the saving in possible damage, in claims and in unnecessary suffering to the animals. It has been found that a series of short blasts on the whistle is often effective in getting animals to move off the track. Another good scheme while steaming is to open the cylinder cocks. At night the headlight often blinds animals, so that drivers should dim the light or turn it right out as soon as animals are seen on or near the track. (See *Train Working Regulation No 175*).

Frightening of animals which are well clear of the track or even outside the railway fence, is both foolish and cruel, and may involve the Administration in claims if the animals are injured, which may easily happen. Cases have occurred where enginemen have opened the blowdown cock on purpose to frighten cattle or game which are on a farmer's land: such action is foolish and irregular.

Shunting operations must always be carried out with care by all concerned, including enginemen, and it must be emphasized that the provisions of *Train Working Regulations Nos 128, 134, 141, 142, 143, 144 & 145*, as well as of *Clause 45(10), Section II and Clauses 1, 3, 4, 5 & 6, Section IX of the General Appendix (Part 1)* must be observed at all times. Drivers must see that sufficient brake power is available to control the movements properly, and further that vehicles are not allowed to collide when they are being coupled. While it is most important not to waste time by moving unnecessarily slowly or by failing to respond promptly to signals, drivers must not go to the other extreme and travel at a dangerous speed. Particular care must be taken when kicking off trucks to ensure that excessive speeds are not reached, and it must always be remembered by enginemen that shunters can easily misjudge the speed of an approaching load. Drivers should satisfy themselves that vehicles kicked off are not travelling too fast for the shunters to be able to reach them and operate the hand brakes.

The greatest vigilance on the part of both driver and fireman is absolutely essential if shunting operations are to be carried out with is safety to the servants concerned and to vehicles and their con tents. An immense amount of very expensive and quite unnecessary damage is done while shunting.

A sound knowledge of the regulations and instructions, including those contained in Local Appendices and Working Time Books, is absolutely essential for safe working - see *Train Working Regulations Nos 4 & 5*. Any

amendments issued must promptly be pasted into the books concerned. Enginemen must realize that those portions of the regulations and instructions with which they are not frequently concerned are liable to be forgotten quite quickly, so that every effort must be made to keep their knowledge up-to-date. One of the best ways of doing this is to take every opportunity of teaching the firemen working with them, and to make absolutely sure that the teaching is correct. A well trained fireman is of great value and assistance to a driver, and such men have saved many serious accidents. Enginemen should note the provisions of *Clause 12, Section II of the General Appendix (Part 1).* It must be emphasized that lack of knowledge of the regulations and instructions will never be accepted as an excuse for failure to observe them.

On the locomotive the driver is in sole charge, and the fireman is not only under his orders, but also under his supervision, with the result that in almost all circumstances the driver must carry the full responsibility. See *Train Working Regulation No 166(1).* Drivers must, in their own interests, and in those of the Administration, always bear these points in mind. A friendly and co-operative attitude between the driver and the fireman is most important for good working, but undue familiarity will always result in trouble, or even in disaster, eventually. Wrestling and other forms of horseplay or practical joking on the footplate or anywhere on Railway premises cannot be too strongly condemned from the point of view of safety, and of good advertisement in the eyes of the public.

Cleanliness on the footplate is of great importance for safety, as oil or lumps of coal can easily cause one of the crew to slip, and dust will sooner or later get in the eyes. A dirty footplate is a sign of lack of interest on the part of the driver, and it is no use trying to put all the blame on the fireman.

If an organization such as the South African Railways is to work even reasonably well, close co-operation between servants is absolutely essential - see Train Working *Regulation No 6 and Clause 33, Section II of the General Appendix (Part 1).* If instructions are given to enginemen, they should be carried out provided no danger or direct contravention of the regulations is involved. It must always be realized that different interpretations of regulations and instructions are sometimes possible, so that a reasonable and sensible attitude must be adopted. In addition, co-operation makes working conditions far more pleasant.

When submitting reports, it is most important to give all essential information, not forgetting the fact that the officer dealing with the matter most probably knows nothing about it until he sees the report. Discussing the matter with the Locomotive Foreman, Locomotive Inspector or Running Foreman will often help enginemen to submit an accurate report. The time at

which an incident occurred is often of vital importance, so that it should be a regular practice to note the time and to mention it, together with the date, on the report. (See **Section 11** of this Handbook.) It is most useful for enginemen to carry a notebook with them all the time they are on duty, so that particulars which can easily be forgotten, such as time, mileage, truck numbers and so on can be written down on the spot. This notebook is also essential for the accurate booking of repairs to the locomotive. The attention of enginemen is drawn to *Train Working Regulation No 201*. The *Trainmen's Report Form, T.489*, is handy for submitting reports, particularly if the printed portion near the top is fully filled in.

As previously mentioned, the starting of a train must be done with great care to avoid jerks, particularly when the train is bunched through shunting. If the load is not very heavy, as in the case of a passenger train, the regulator should be opened steadily until the train begins to move, and then should be eased until the load has been properly picked up. The regulator should then be opened more and more so as to give the desired acceleration without causing the engine to slip. With a heavy load, or on a rising grade, it is usually necessary to 'pump' the regulator handle to some extent, that is, to open it about a third to halfway until the first exhaust beat is heard, then ease it for a moment, open it again part way until the next beat is heard, ease it again and so on until the load is moving freely. Cut-off should be shortened a little at a time. The steam chest pressure gauge is a most useful fitting when starting a train. When it is desired to start steaming after drifting down a gradient, the regulator must be opened before the engine reaches the bottom of the bank, so that the train does not get a chance to bunch up. The regulator should be opened steadily until the exhaust beats can be heard, and then the reversing gear should be placed in the most suitable cut-off, after which the regulator should be opened as much as is necessary.

If the engine will not pick up the load it is first essential to make certain that the brakes are fully released throughout the train. If the engine still refuses to lift the load, the cylinder cocks should be opened and the reversing gear should be moved slowly until the locomotive begins to move backwards. A movement of about one-eighth of a revolution of the coupled wheels is normally quite sufficient, and will compress three or four buffers. The reversing gear should then be placed in about 15 per cent fore-gear until the slack has been almost completely taken up, after which it should be dropped out into full fore-gear, and the regulator opened sufficiently to get the train moving. This operation requires great care and considerable skill if severe jerking and broken buffers are to be avoided, but is not often necessary.

In the past it was the practice on the S.A.R., to allocate locomotives as far as possible to individual drivers. This method had considerable advantages, but in recent years the Administration has been forced, mainly by economic

considerations, to resort to extensive pooling, and it can be stated that this has come to stay. A locomotive which in the past cost about £9,000, now costs about £60,000, so that it will readily be seen that if the majority of drivers had regular engines, huge amounts of money would be lying idle. In common with other railways all over the world, the S.A.R. cannot afford this, and has had to use its locomotives as intensively as possible. The organization of the running sheds is being modified as rapidly as possible to make it more suitable for dealing with pooled engines.

Enginemen should adapt themselves to the changed conditions and must realize that if they do not look after the locomotives placed in their charge, the traffic offering cannot be moved, and the revenue of the Administration will drop. It is only by moving every ton of traffic possible that the Railways earn sufficient money to pay its servants, and further if the transport system were to break down, the whole country would face economic and financial disaster. It is therefore essential for enginemen and all other railway servants to look after their jobs conscientiously.

After a fair amount of experience, it will be found that the driving of a locomotive becomes nearly as automatic as the driving of a motor car, so that the signs of a good driver are:

1. Invariable good timekeeping.
2. The ability and willingness to make up time when it is safe to do so.
3. Continuous alertness, both physical and mental.
4. Smooth and steady handling of all trains.
5. The absence of large volumes of black smoke.

Any man who has real interest in and enthusiasm for his job can develop these characteristics, and will soon find that he has an excellent reputation.

Enginemen are in a position of trust and of great responsibility and have gained the confidence of the public over many years. It should be their constant endeavour to see that this confidence is at all times fully justified and to enhance whenever possible the reputation for reliability and steadiness which they enjoy as a group.

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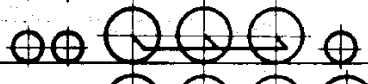
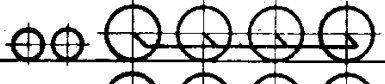
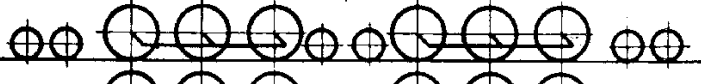
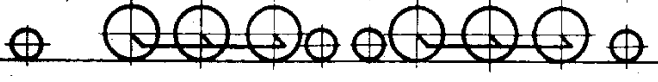
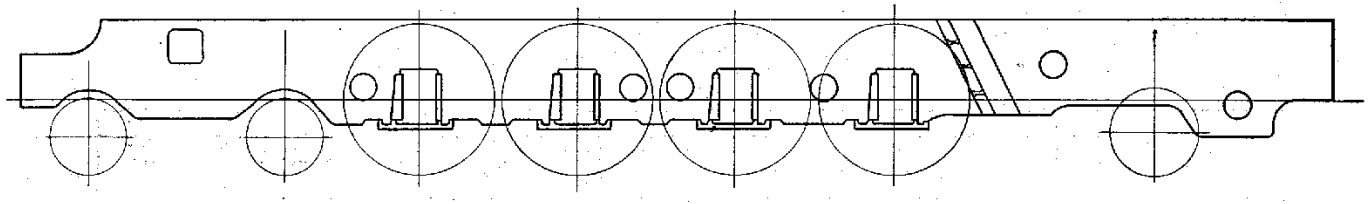
ARRANGEMENT RANGSKIKKING	TYPE TIPE	EXAMPLE VOORBEELD
	4-6-0.	CLASS / KLAS 6.
	4-6-2.	.. 16DA.
	4-8-0.	.. 8.
	4-8-2.	.. 15F.
	2-8-2	.. 11.
	0-8-0	.. S.
	4-6-2+2-6-4.	.. GF.
	2-6-2+2-6-2.	GCA.

FIG. I. EXAMPLES OF WHEEL ARRANGEMENTS
SKETS. I. VOORBEELDE VAN WIEL RANGSKIKKING



SKETS. 2. PLAATRAAM.
FIG. 2. PLATE FRAME.

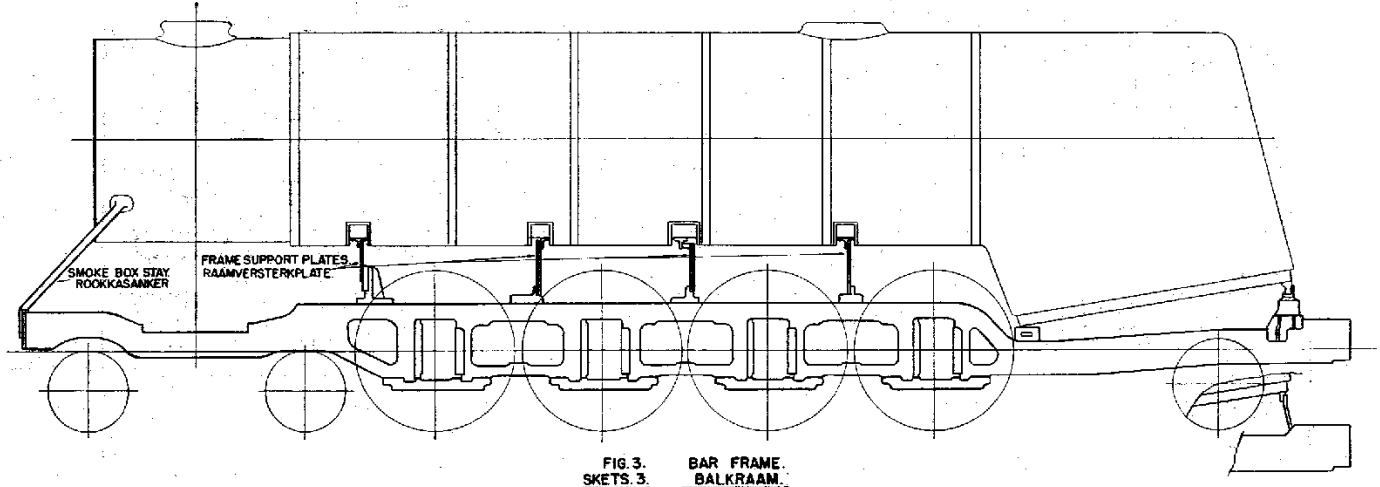
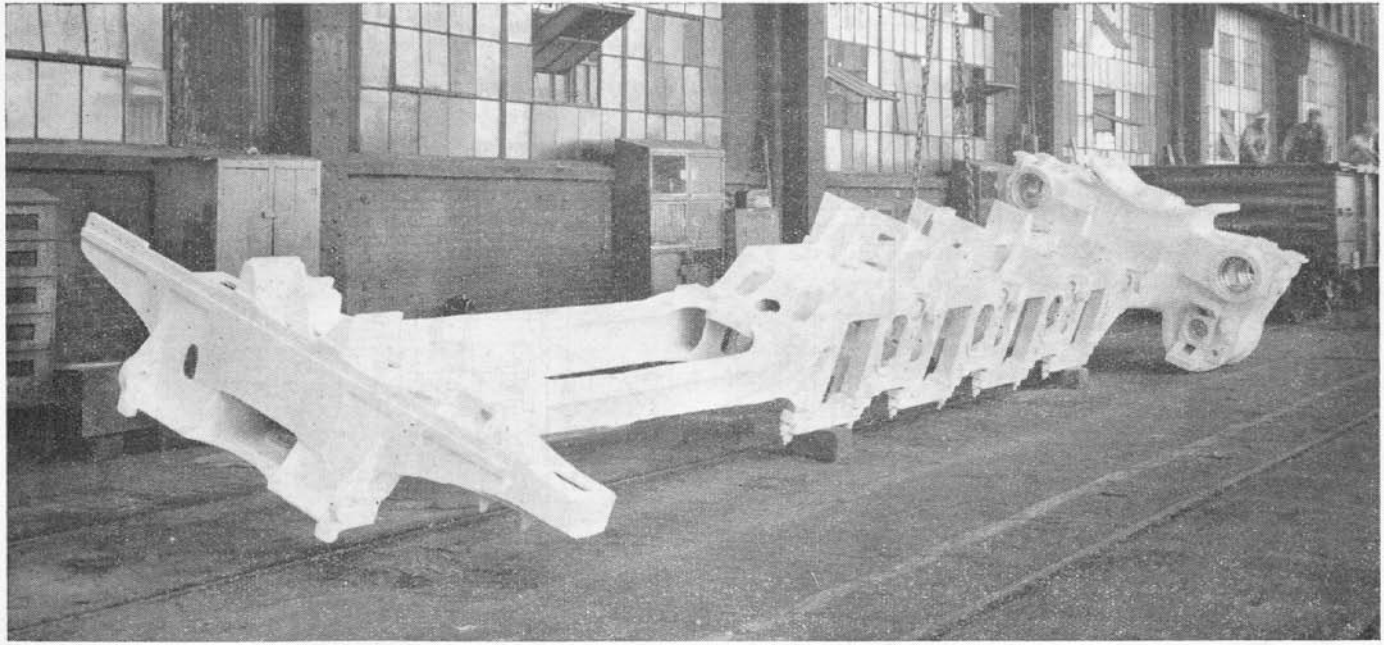


FIG. 3. BAR FRAME.
SKETS. 3. BALKRAAM.



SKETS 4. GEGOTE-STAALRAAM.
FIG. 4. CAST STEEL FRAME.

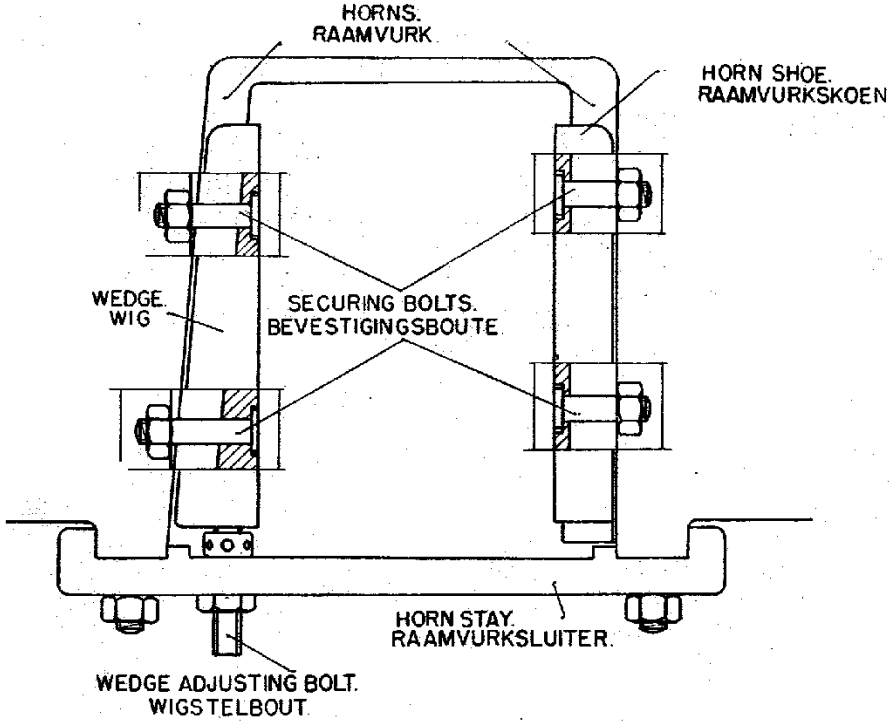
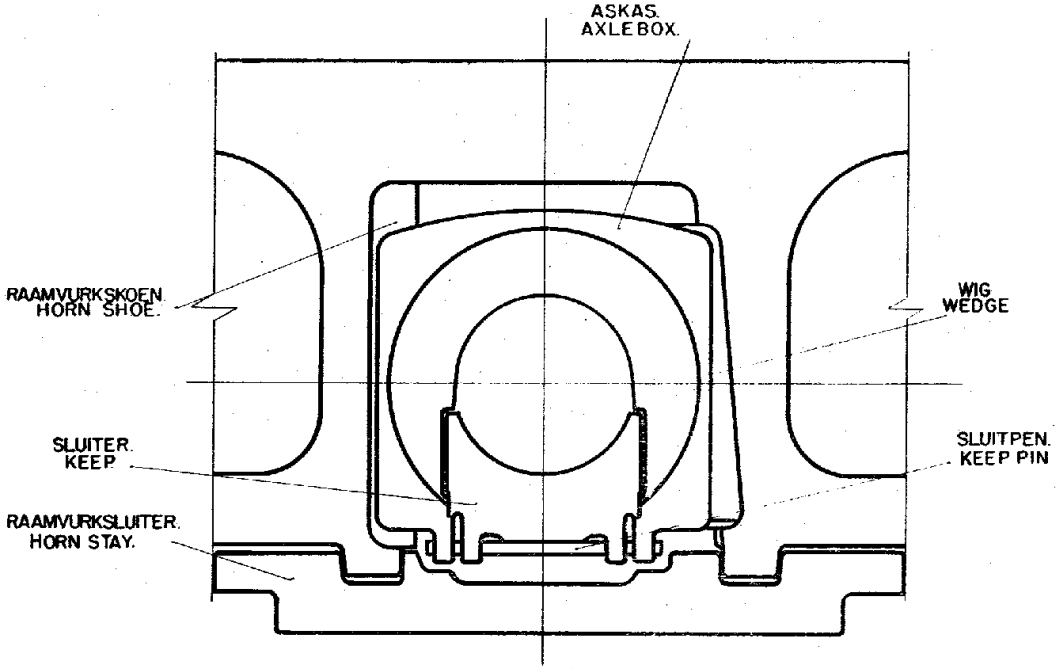


FIG. 5 – HORN WITH SHOE, WEDGE AND STAY.
SKETS 5 — RAAMVURK MET SKOEN, WIG EN VURKSLUITER.



SKETS 6. ASKAS IN POSISIE.
FIG. 6. AXLEBOX IN POSITION.

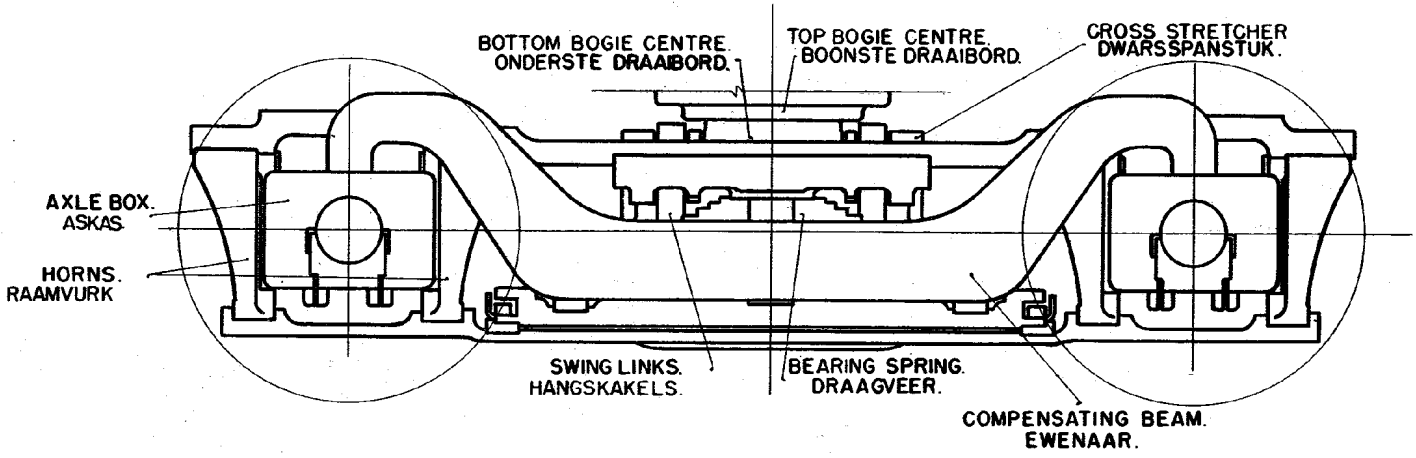
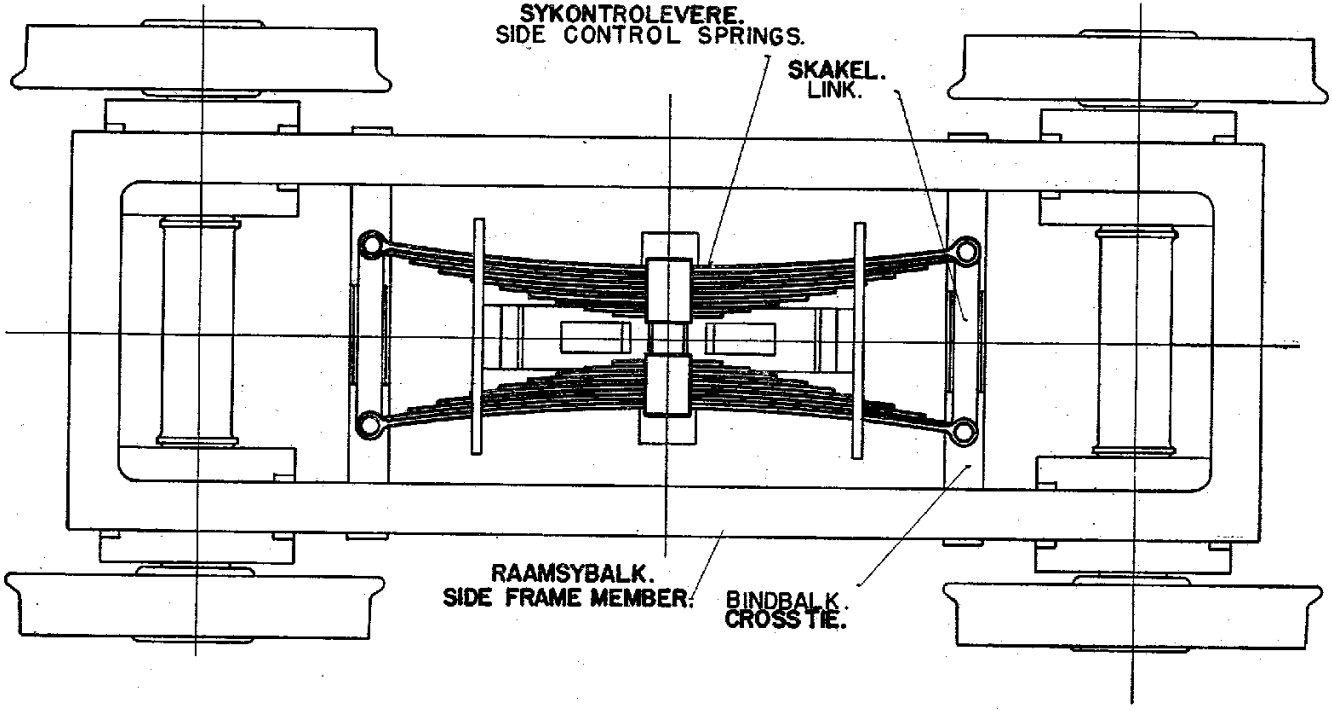


FIG. 7. LEADING BOGIE.
SKETS. 7. VOORDRAAISTEL.

(SEE ALSO FIG. 91
KYK OOK SKETS 91)



SKETS. 8.
FIG. 8

SAMESTELLING VAN VOORDRAAISTELSYKONTROLE.
LEADING BOGIE SIDE CONTROL ARRANGEMENT.

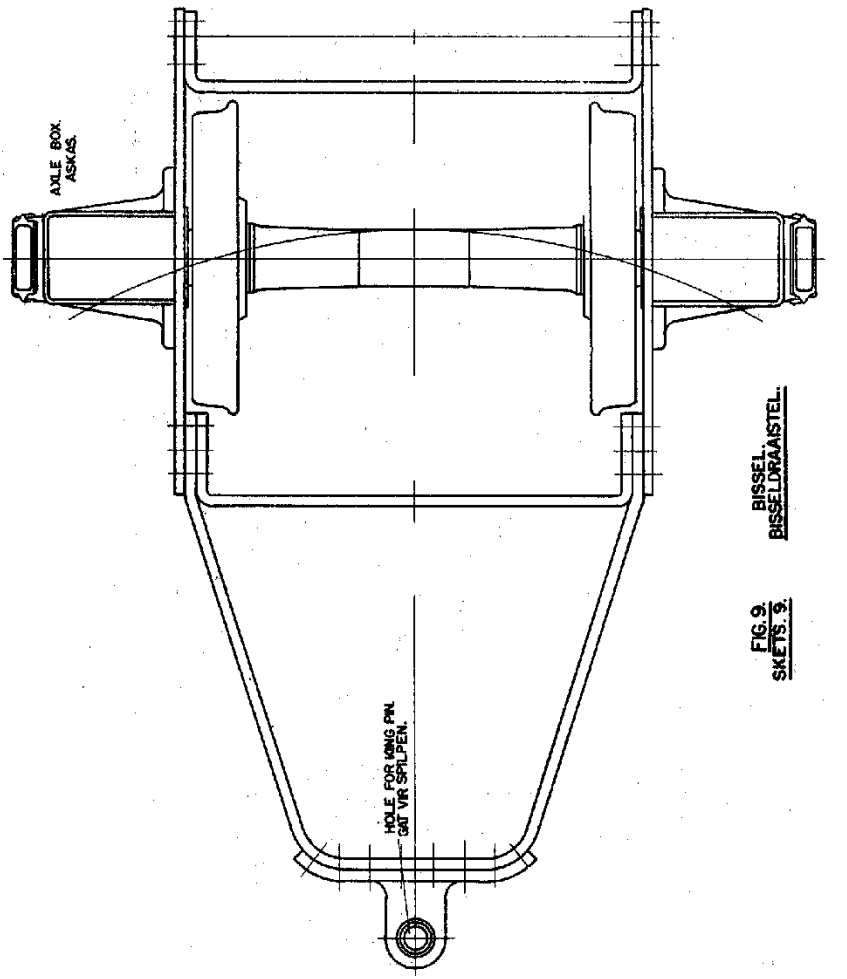
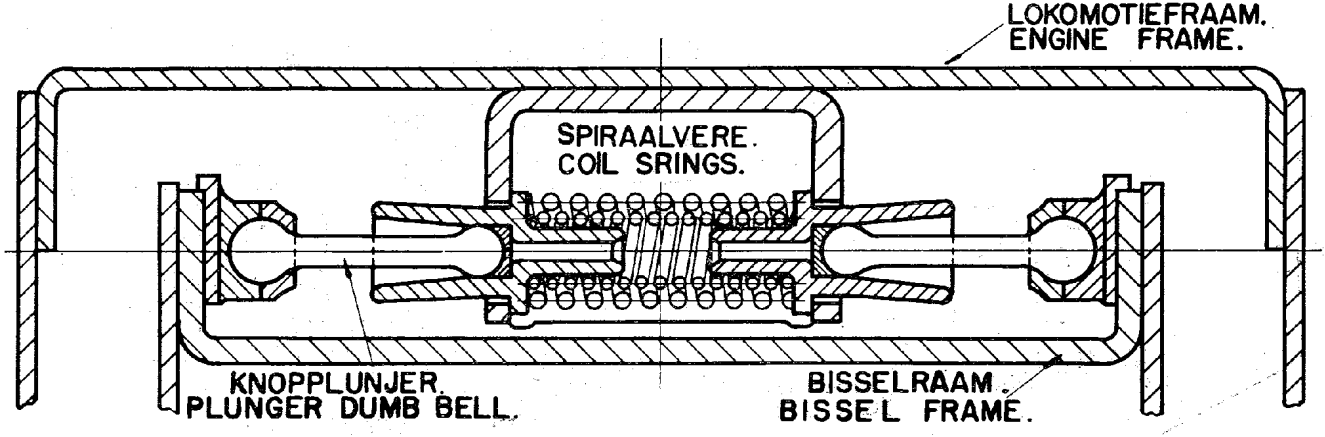


FIG. 9.
SKETS. 9.

BISSEL.
BISSELDRAAISTEL.



SKETS 10. BISSELSYKONTROLEWERK.
FIG. 10. BISSEL SIDE CONTROL ARRANGEMENT.

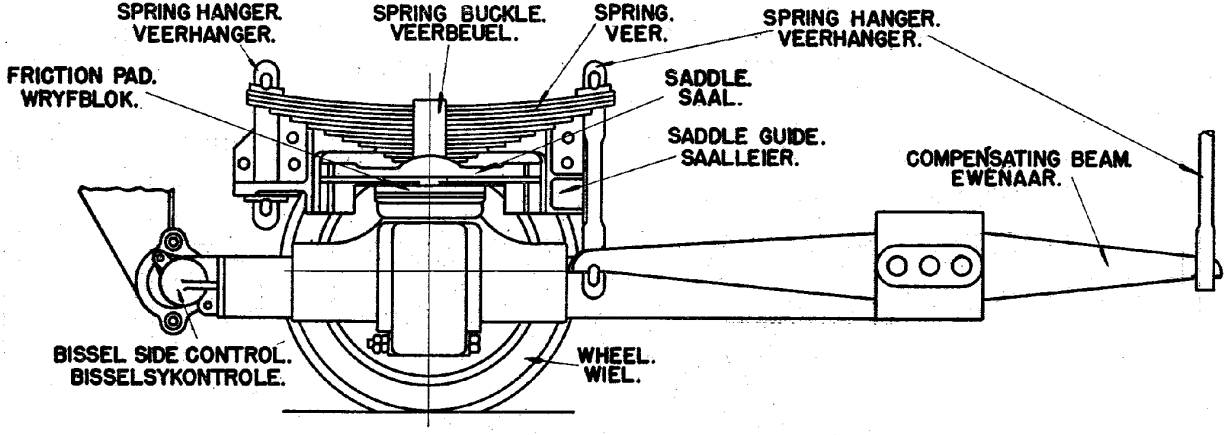
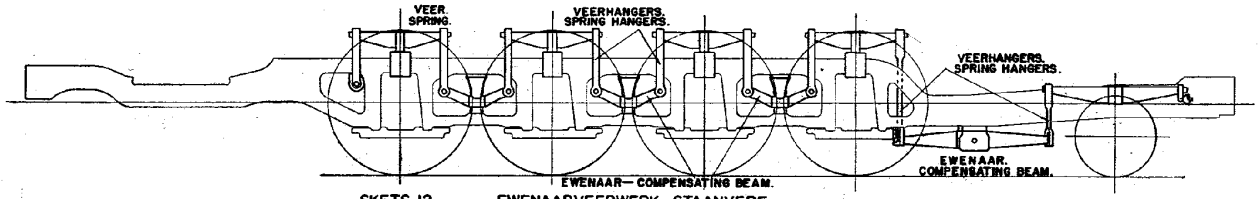


FIG. 11. BISSEL BEARING SPRING RIGGING.
SKETS. 11. BISSELDRAAGVEER-SAMESTELLING.



SKETS 12
FIG.12. EWENAARVEERWERK - STAANVERE.
COMPENSATED SPRING GEAR — OVERHUNG SPRINGS.

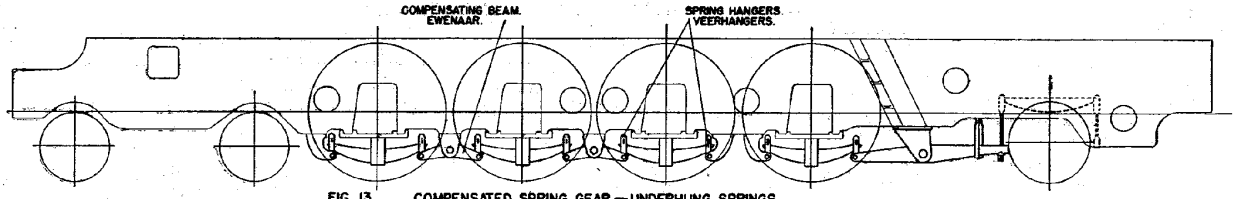
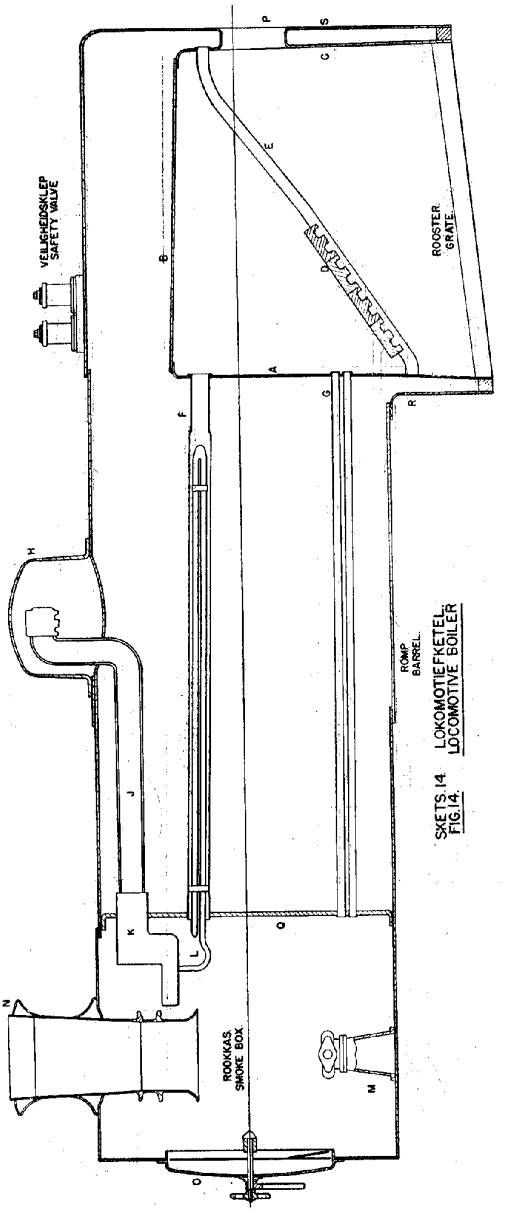


FIG. 13
SKETS. 13. COMPENSATED SPRING GEAR — UNDERHUNG SPRINGS.
EWENAARVEERWERK—HANGVERE.



SKETS. 14.
FIG. 14.
LOKOMOTIEFKETEL.
LOCOMOTIVE BOILER

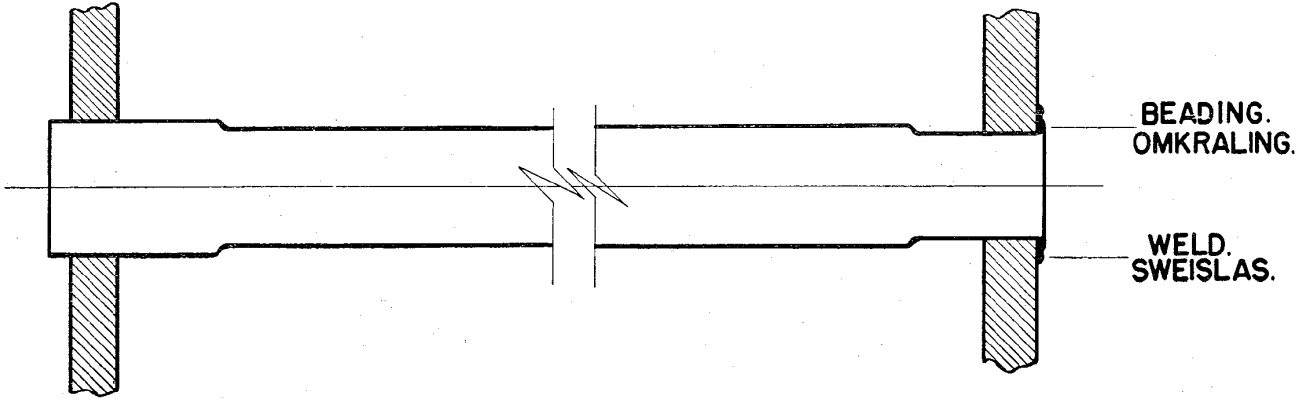
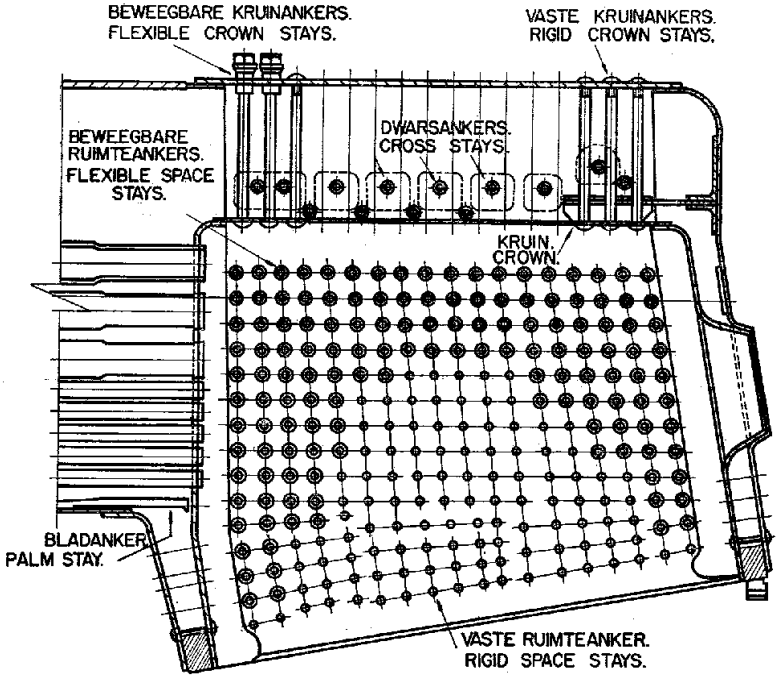


FIG. 15 DETAIL OF METHOD OF SECURING TUBES.
SKETS. 15. DETAILTEKENING VAN HOE KETELPYPE VASGESIT WORD.



SKETS.16 SAMESTELLING VAN VUURKISANKERS.
FIG.16. FIREBOX STAY ARRANGEMENT.

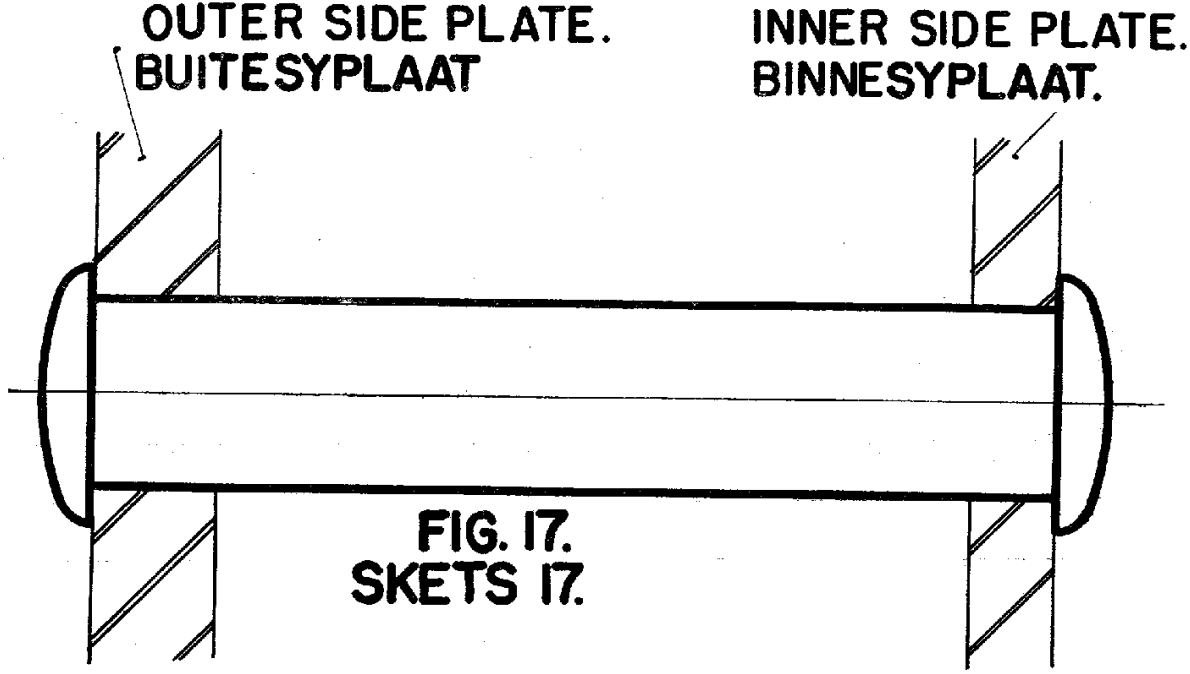
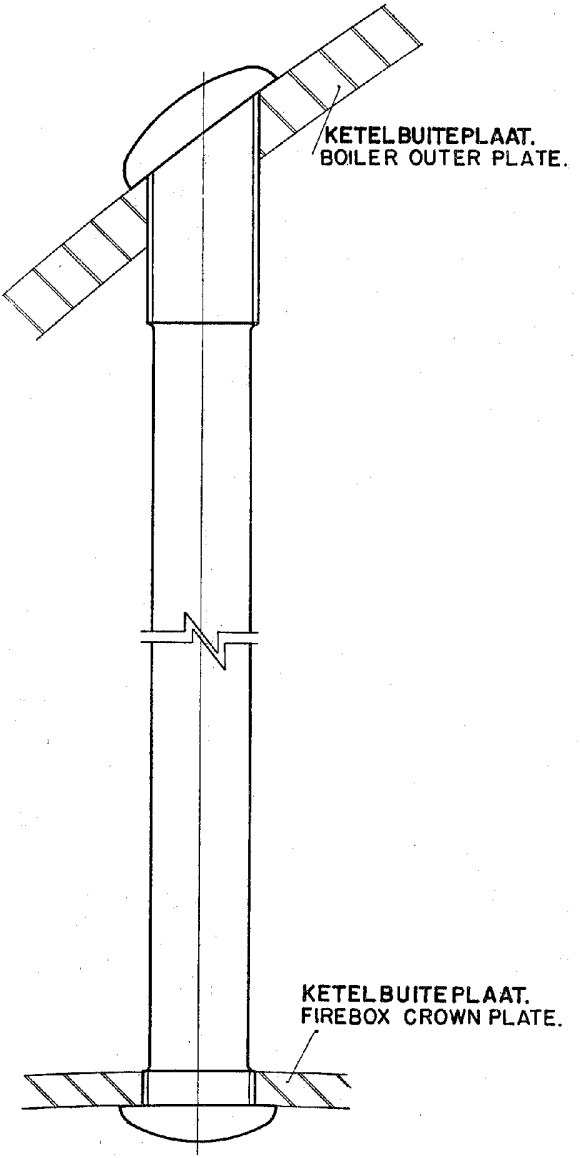


FIG. 17.
SKETS 17.

RIGID SPACE STAY.
VASTE RUIMTEANKER.



SKETS 18 — VASTEKRUINANKER.
FIG 18 — RIGID CROWN STAY.

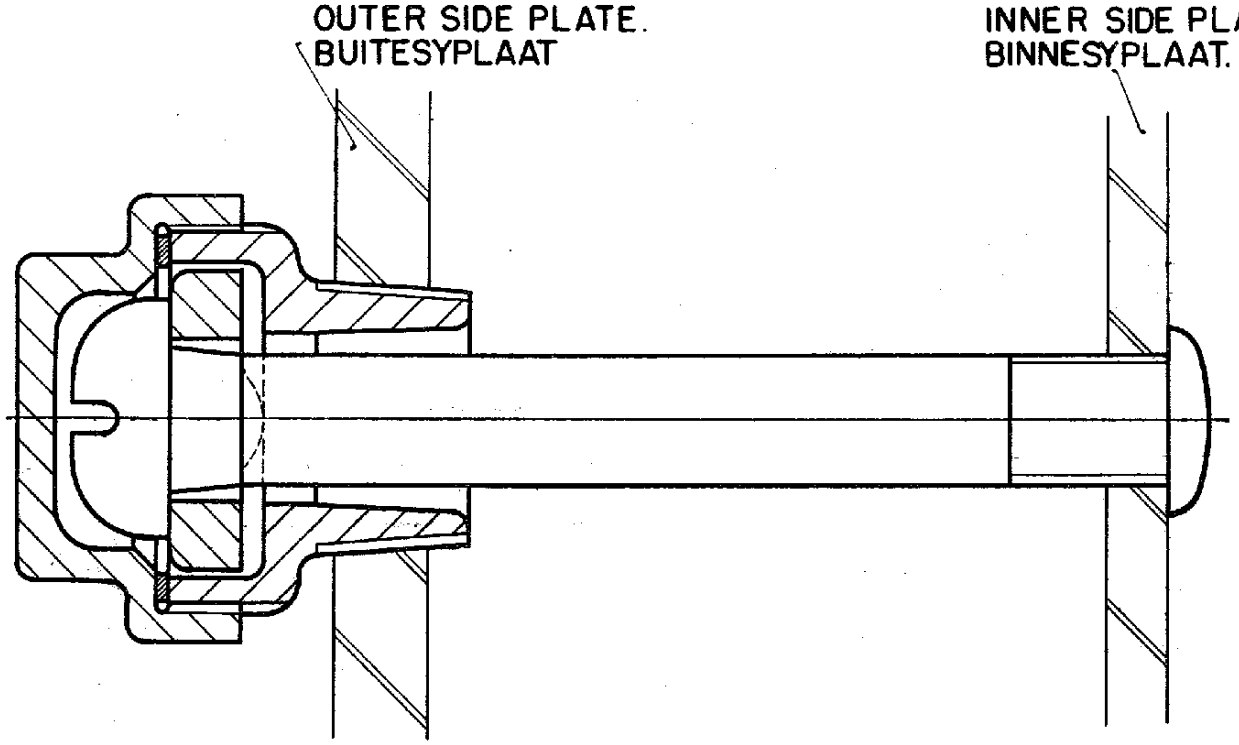
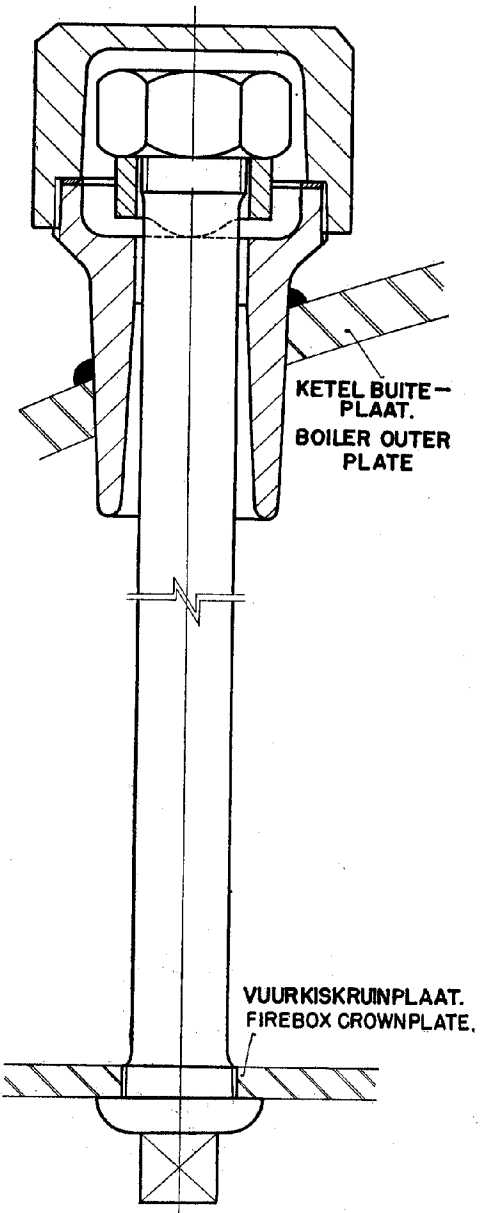


FIG.19. FLEXIBLE SPACE STAY.
SKETS.19. BEWEEGBARE RUIMTEANKER.



SKETS 20 – BEWEEGBARE KRUINANKER.
FIG. 20 – FLEXIBLE CROWN STAY.

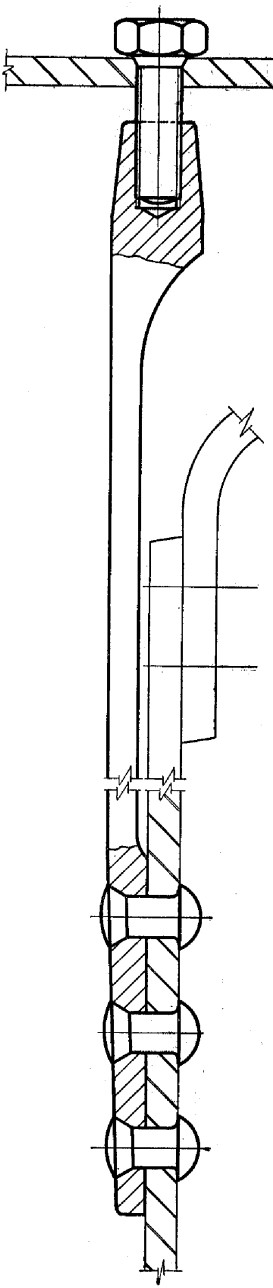
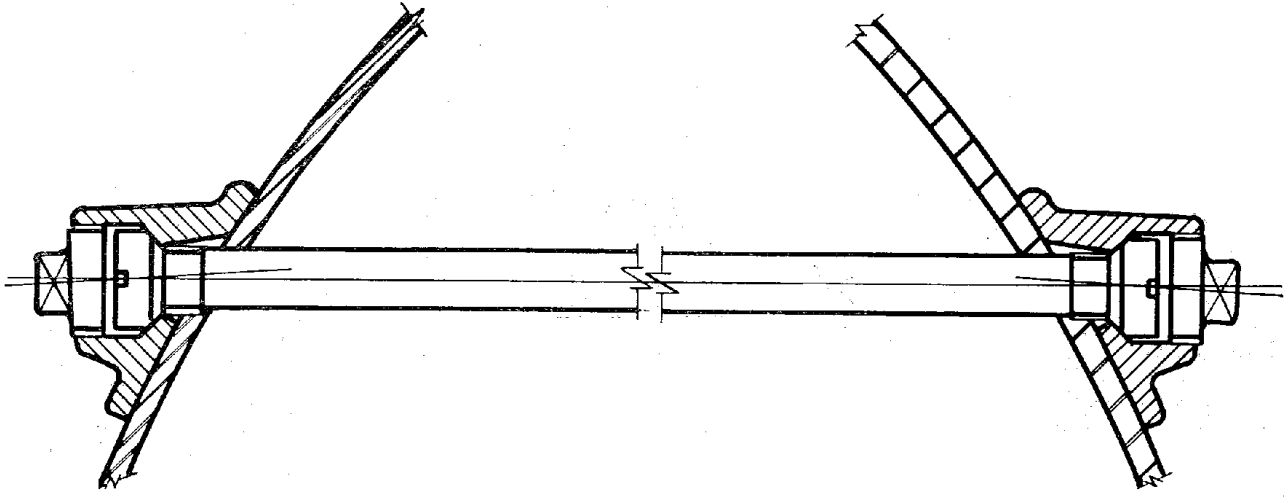


FIG.21. PALM STAY.
SKETS.21. BLADANKER.



SKETS- 22. — DETAILTEKENING DWARSANKER.
FIG.- 22 — DETAIL OF CROSS STAY.

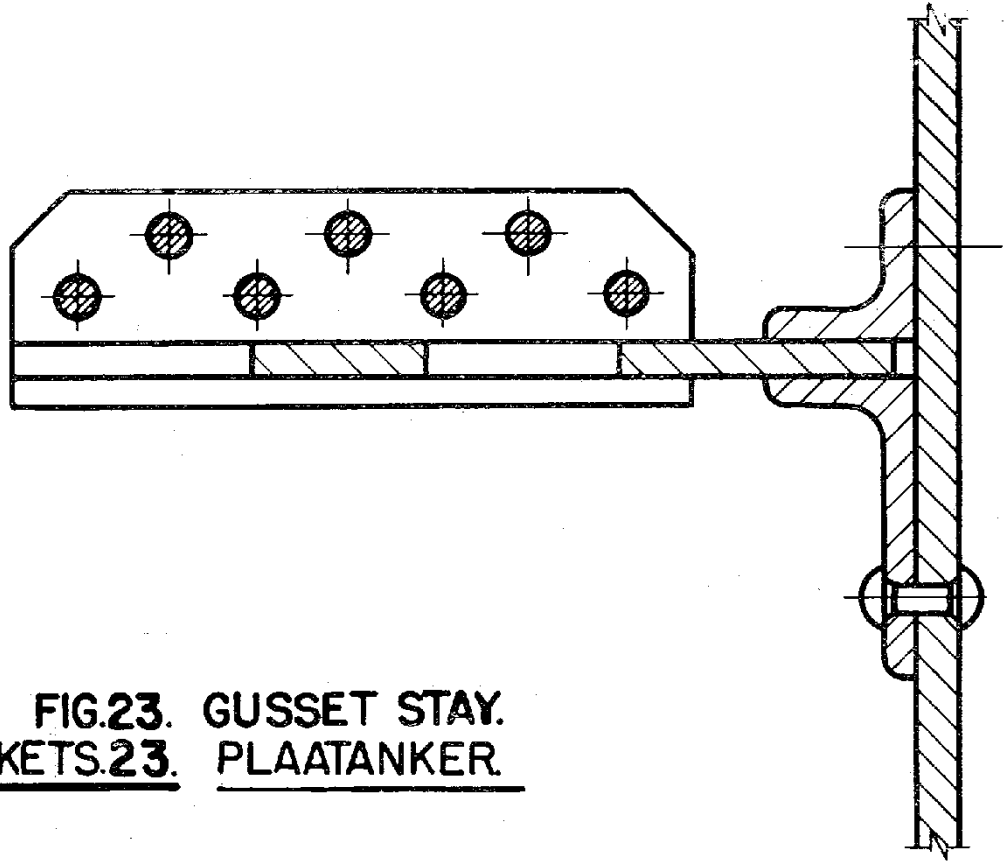
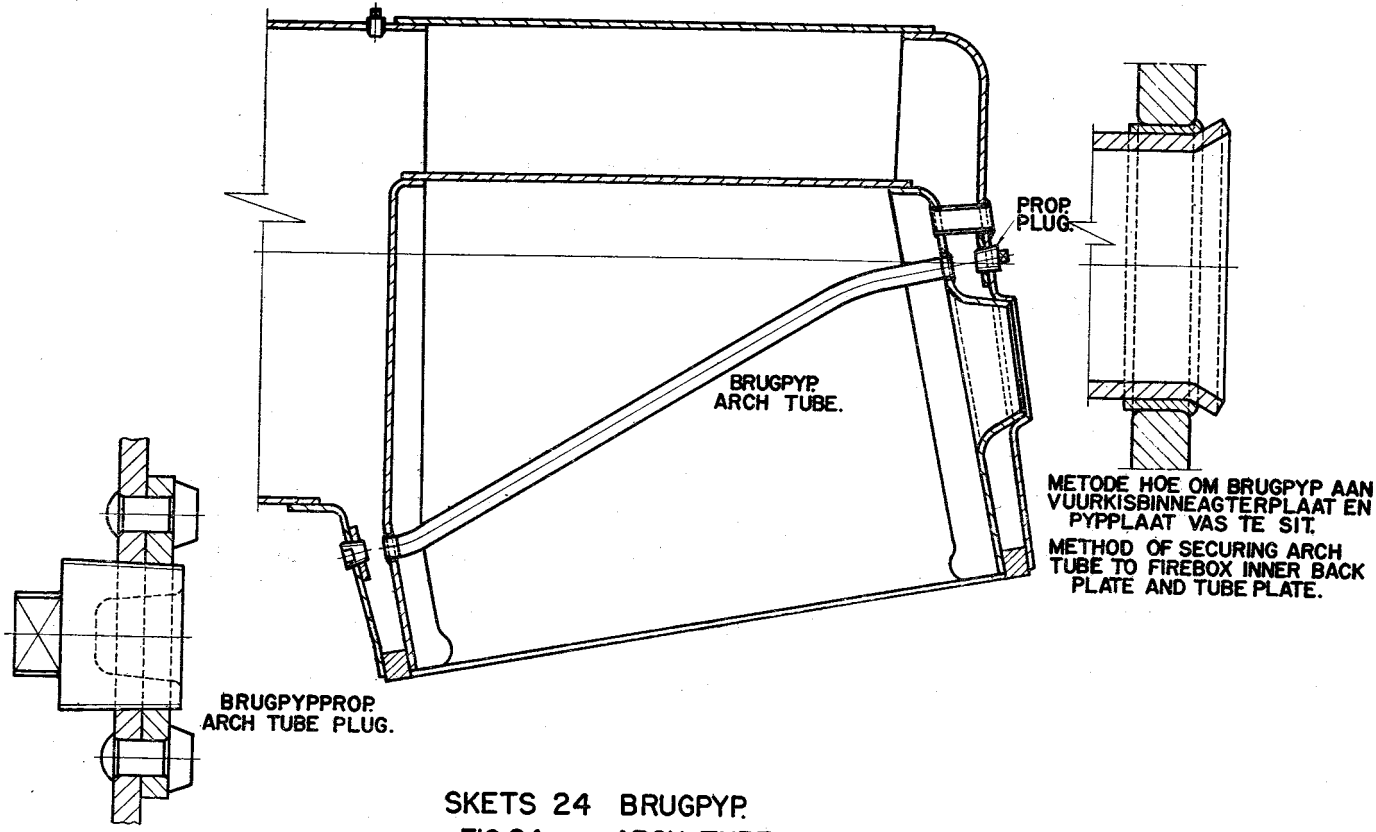


FIG.23. GUSSET STAY.
SKETS.23. PLAATANKER.



SKETS 24 BRUGPYP.
FIG.24. ARCH TUBE.

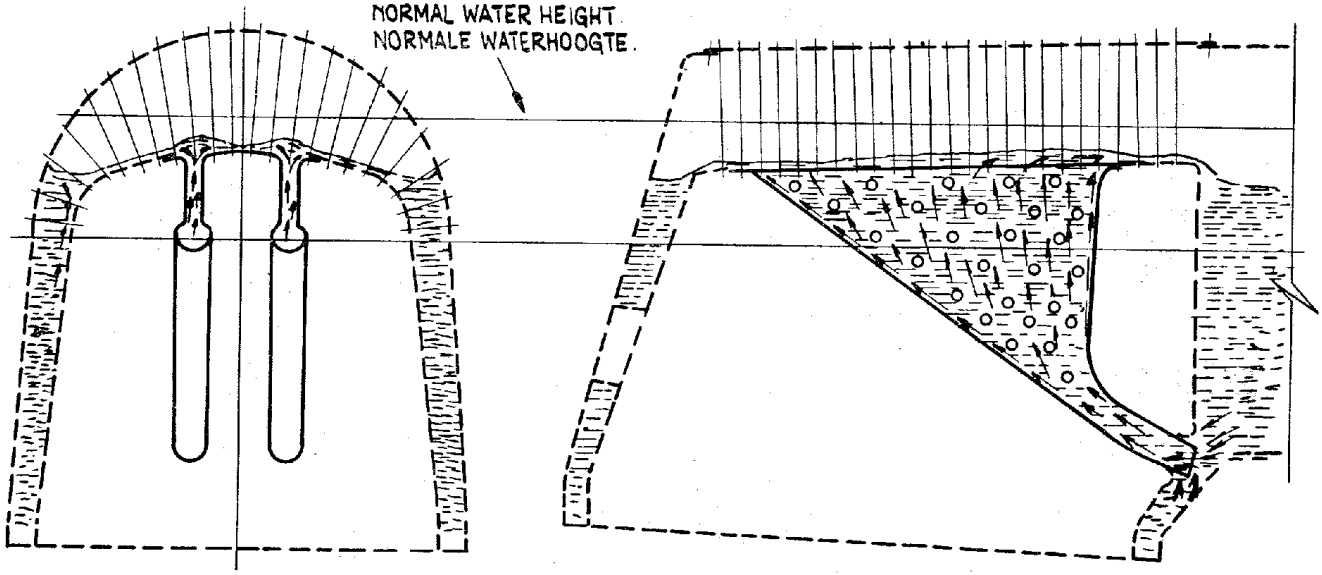
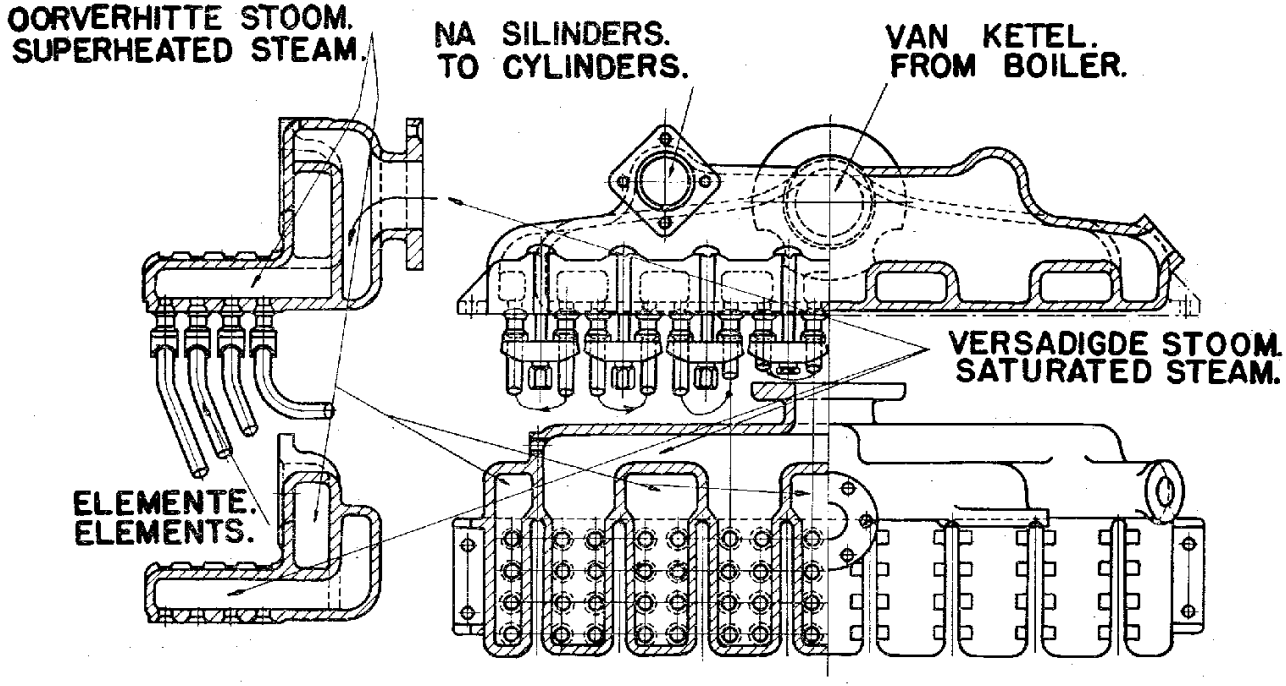


FIG.25. THERMIC SYPHON.
SKETS.25. TERMIESE SIFON.



SKETS 26 OORVERHITTERAFTAKKAS.
FIG.26. SUPERHEATER HEADER.

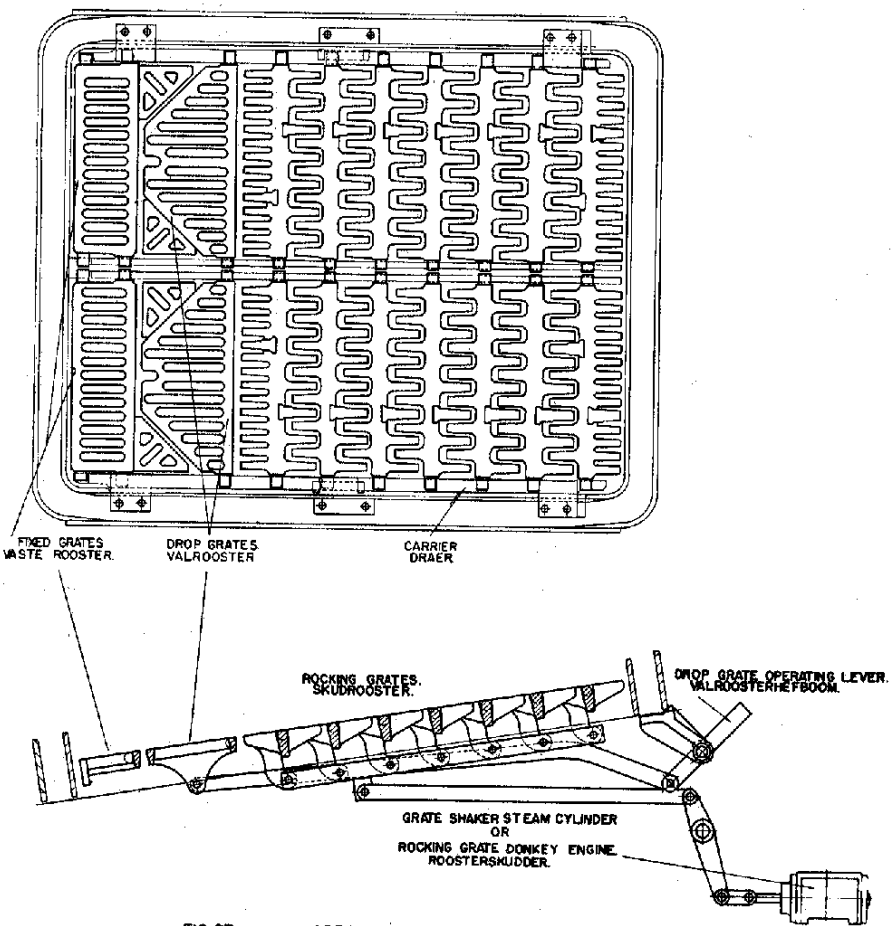
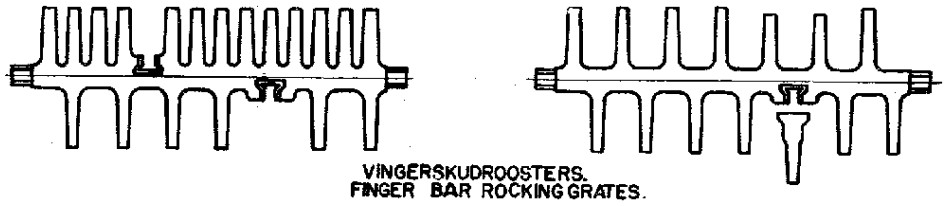
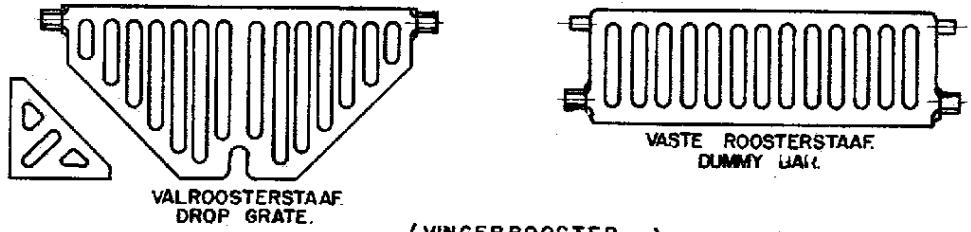
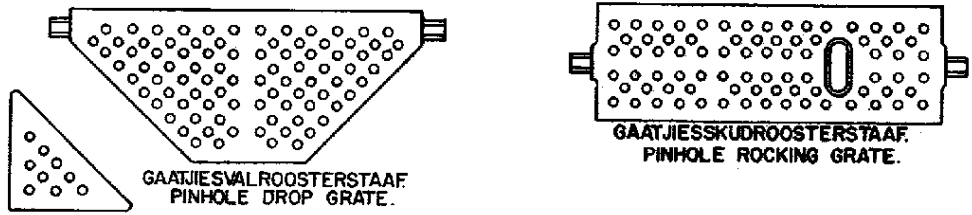


FIG. 27
SKETS 27

ARRANGEMENT OF FIREGRATE
SAMESTELLING VAN ROOSTER







SKETS 28 **TIPES ROOSTERSTAWE.**
FIG. 28. **TYPES OF FIRE BARS.**

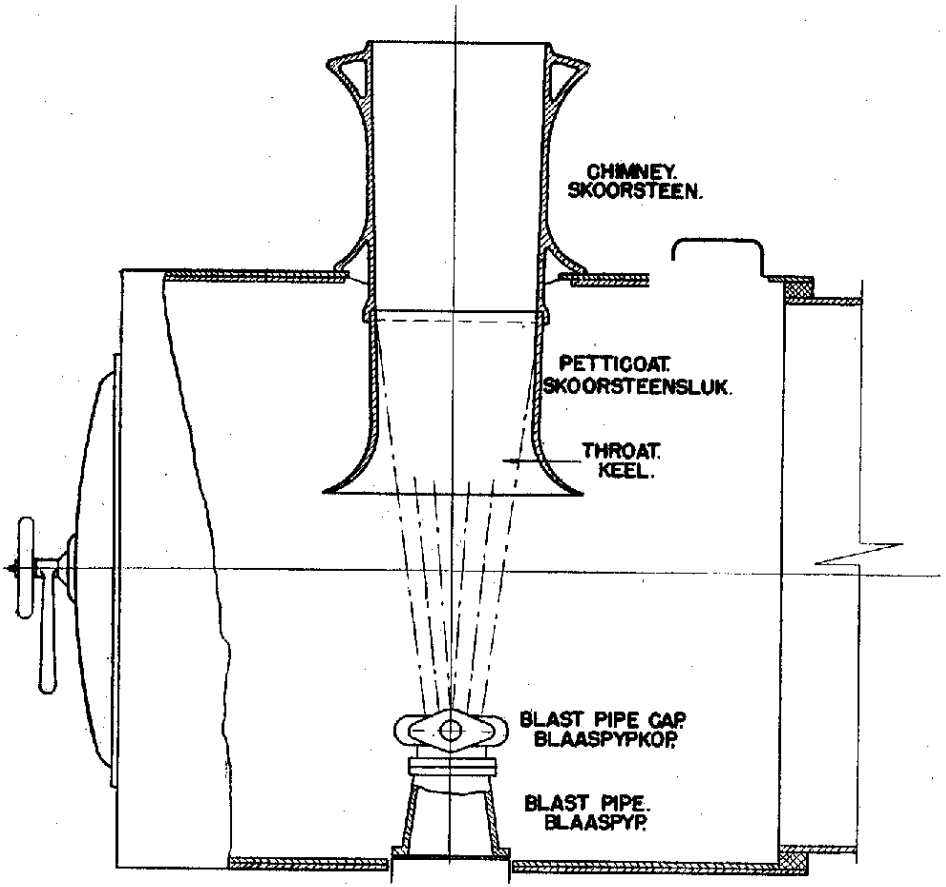
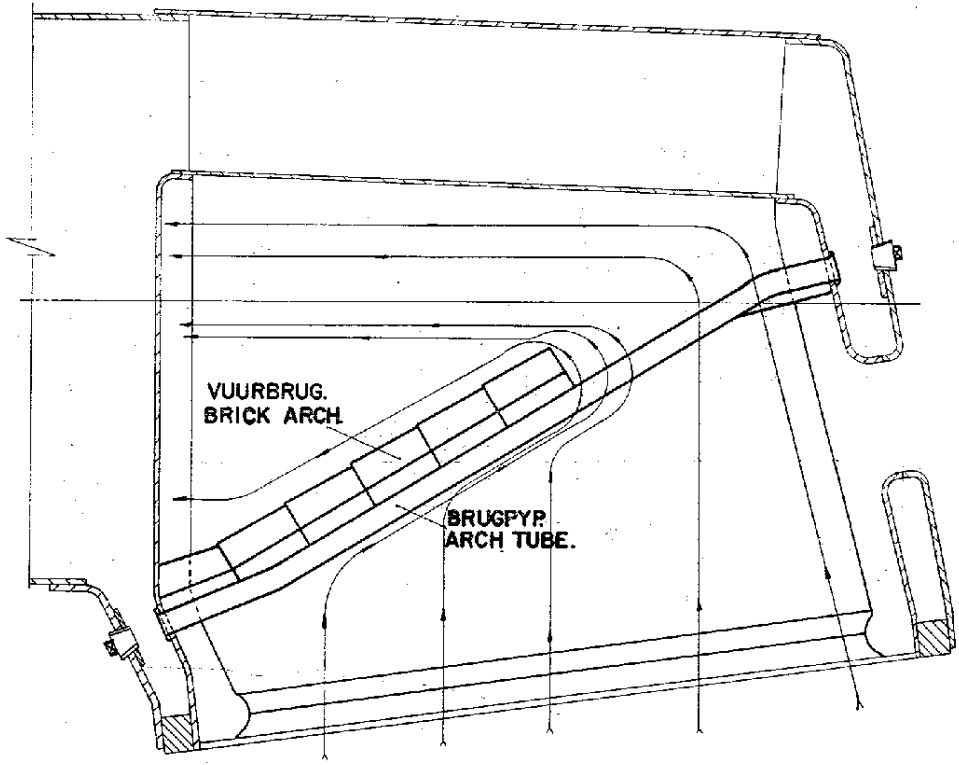


FIG. 29 PRODUCTION OF DRAUGHT IN SMOKEBOX.
SKETS 29. HOE TREK IN ROOKKAS VERKRY WORD.



SKETS 30. SAMESTELLING VAN VUURKIS EN RIGTINGS WAARIN LUGSTROME TREK.

FIG. 30. ARRANGEMENT OF FIREBOX SHOWING DIRECTIONS OF DRAUGHT AND AIR CURRENTS.

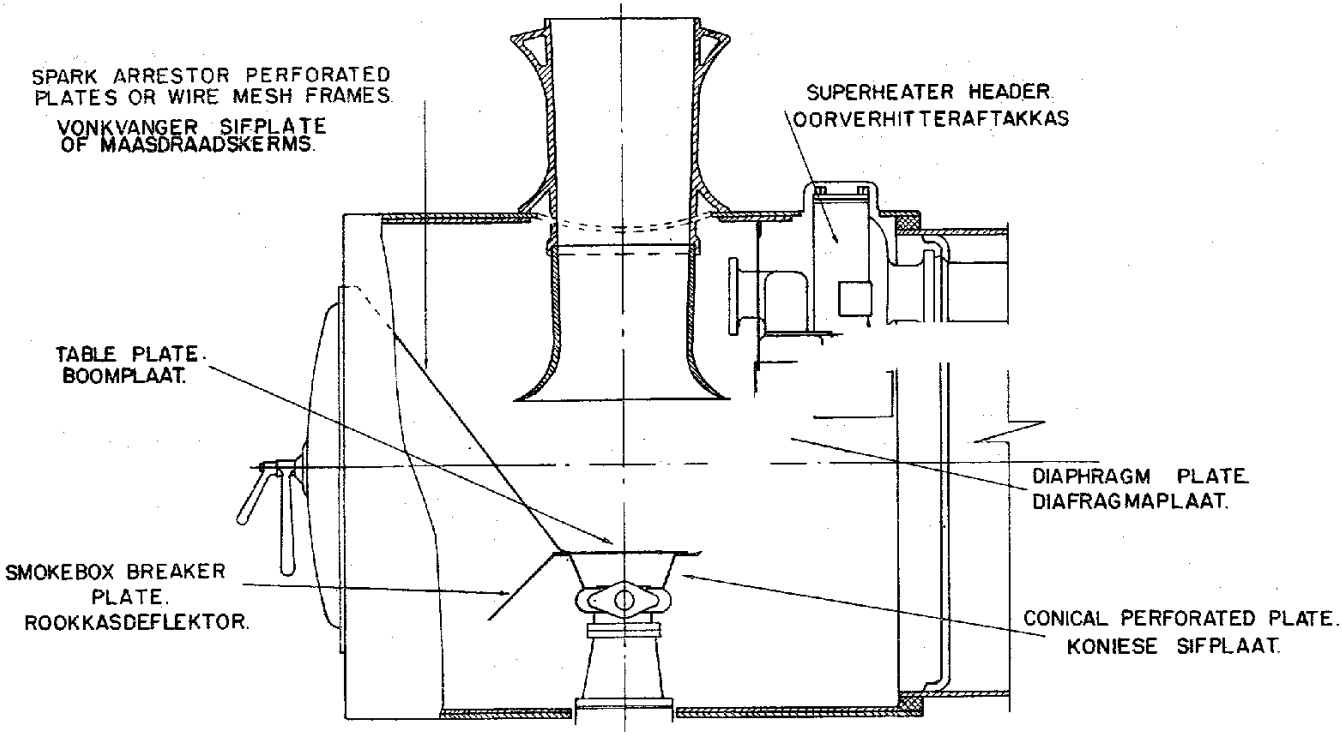
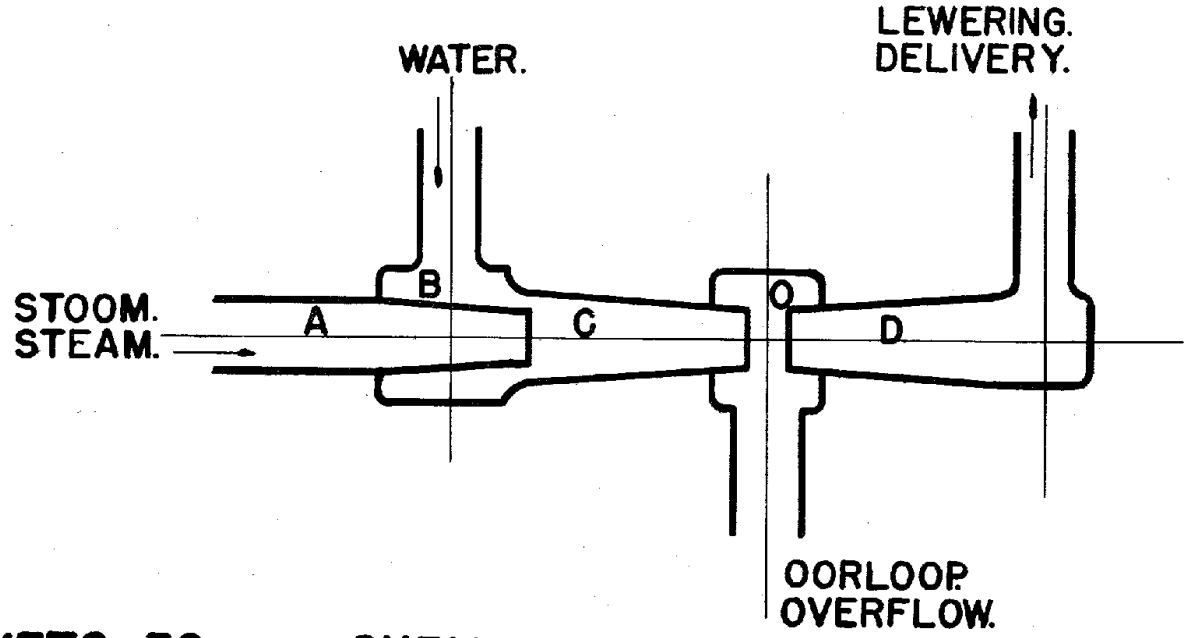
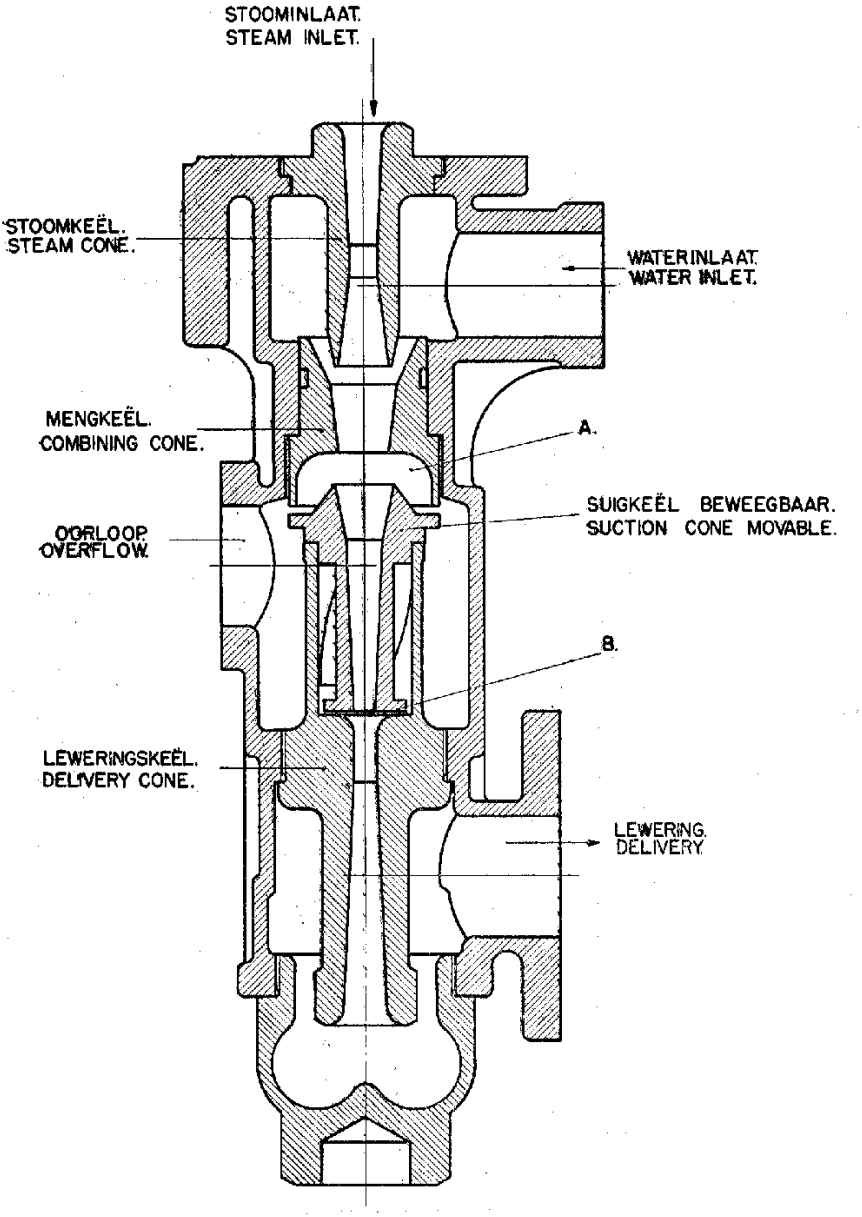


FIG. 31 SPARK ARRESTOR.
SKETS 31 VONKVANGER.



SKETS 32.
FIG. 32.

SKEMATIESE SKETS VAN INJEKTEUR
DIAGRAMMATIC INJECTOR.



SKETS 33 INJEKTEUR.
FIG. 33. INJECTOR.

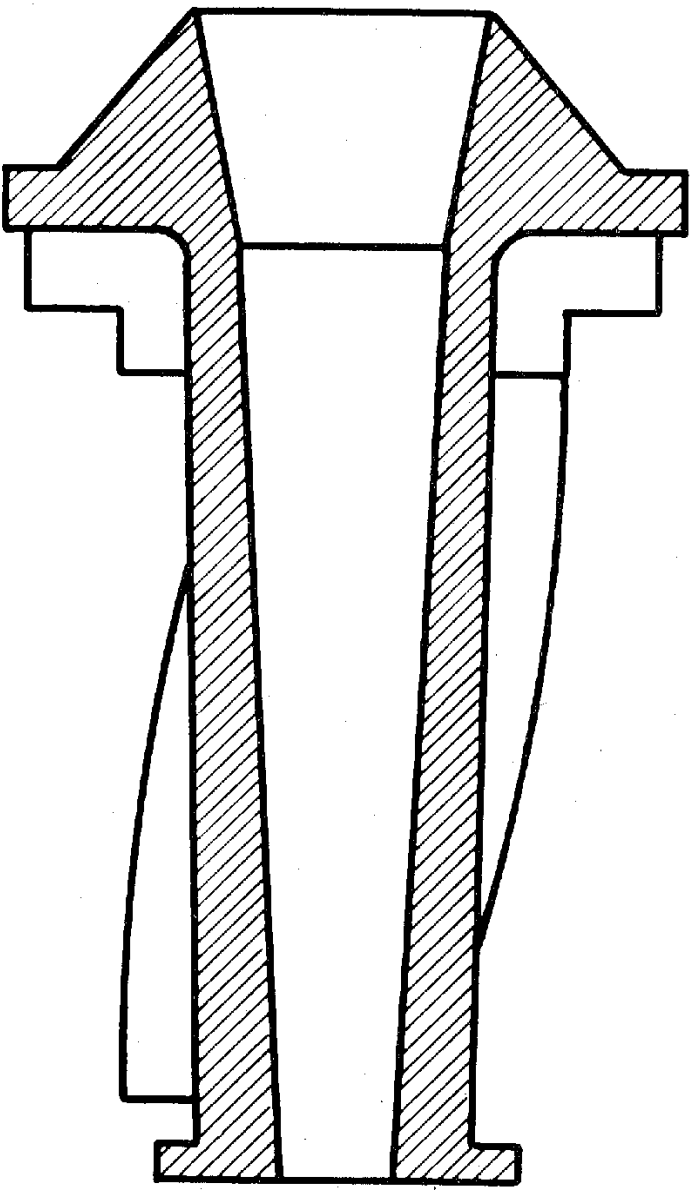


FIG. 34—SUCTION CONE.

SKETS 34—SUIGKEËL

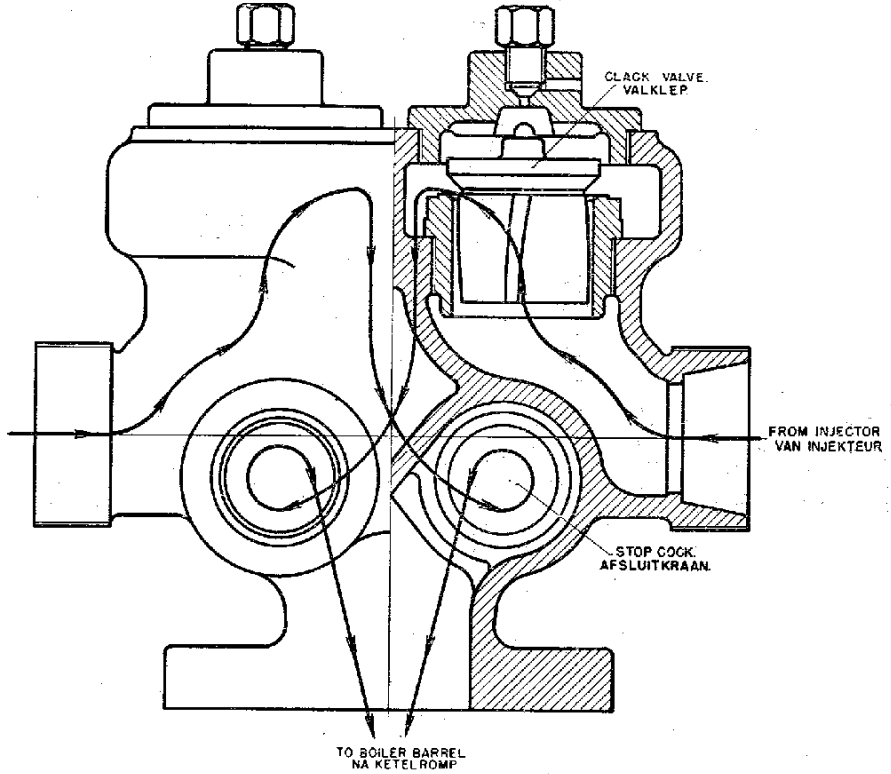
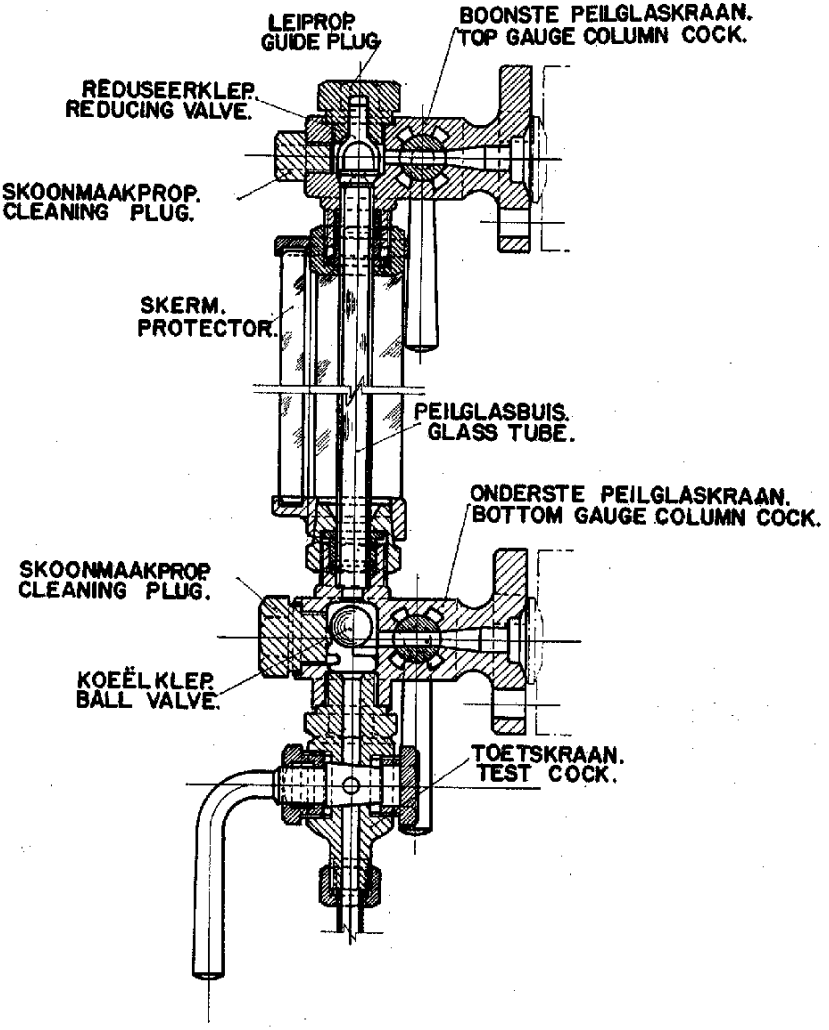


FIG. 35. TOP FEED CLACK BOX.
SKETS 35. KRUINTOEVOERKLEPKAS



SKETS 36. WATERPEILGLAS.
FIG. 36. WATER GAUGE COLUMN.

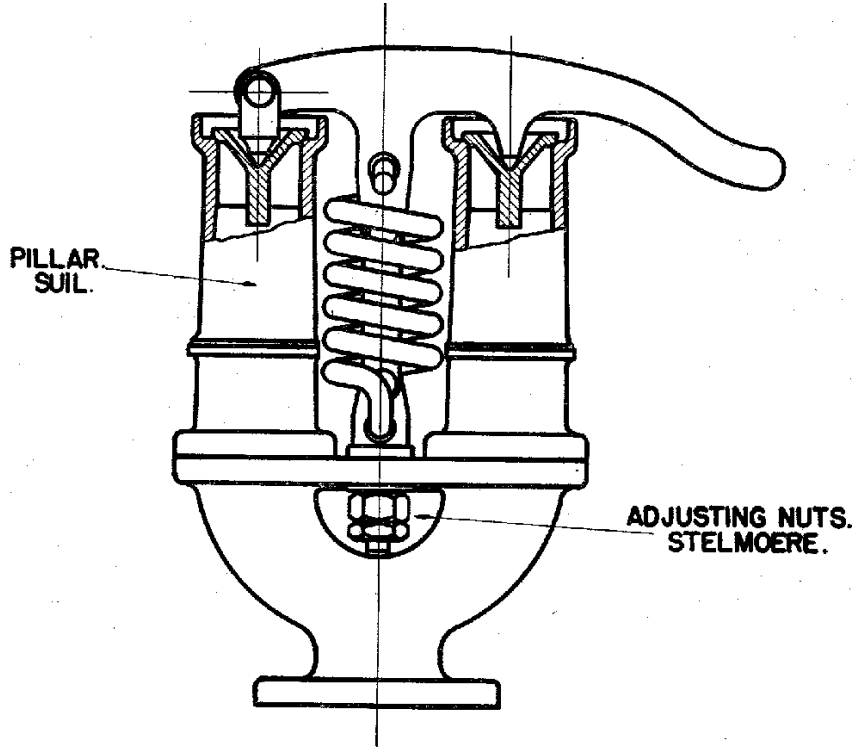
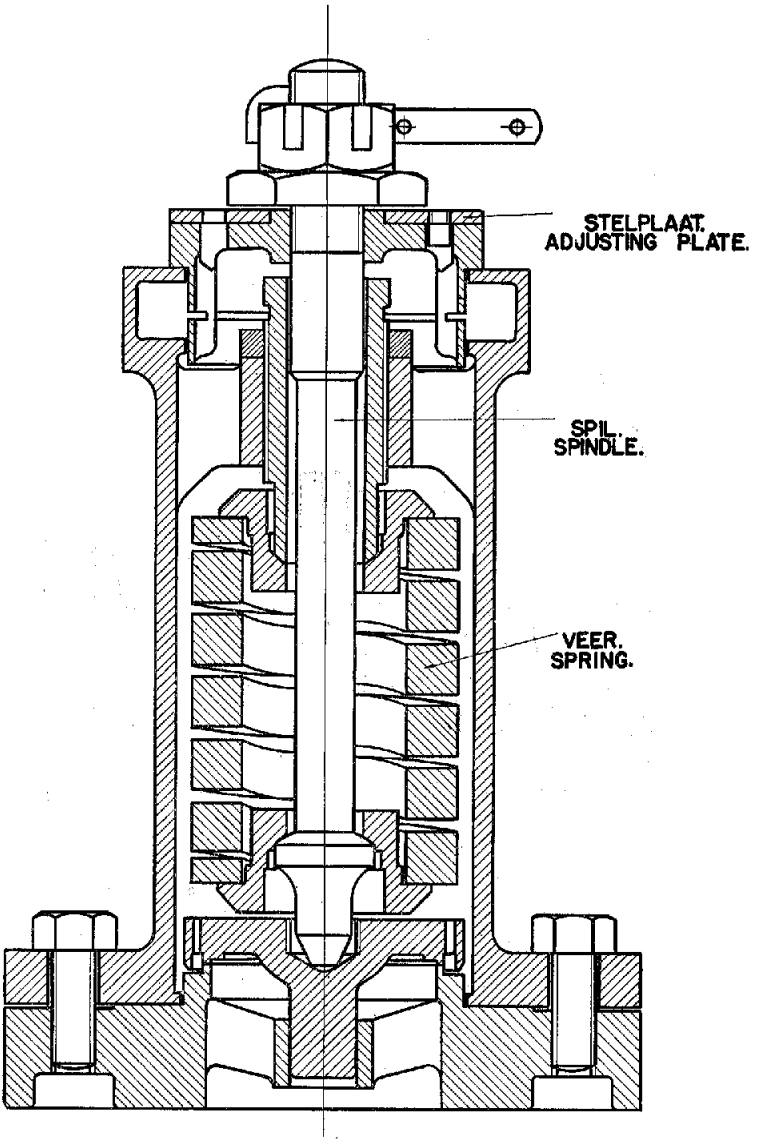


FIG. 37. RAMSBOTTOM SAFETY VALVE.
SKETS 37. RAMSBOTTOM-VEILIGHEIDSKLEP.



SKETS. 38. ROSS – POP VEILIGHEIDSKLEP.
FIG.38. ROSS POP SAFETY VALVE.

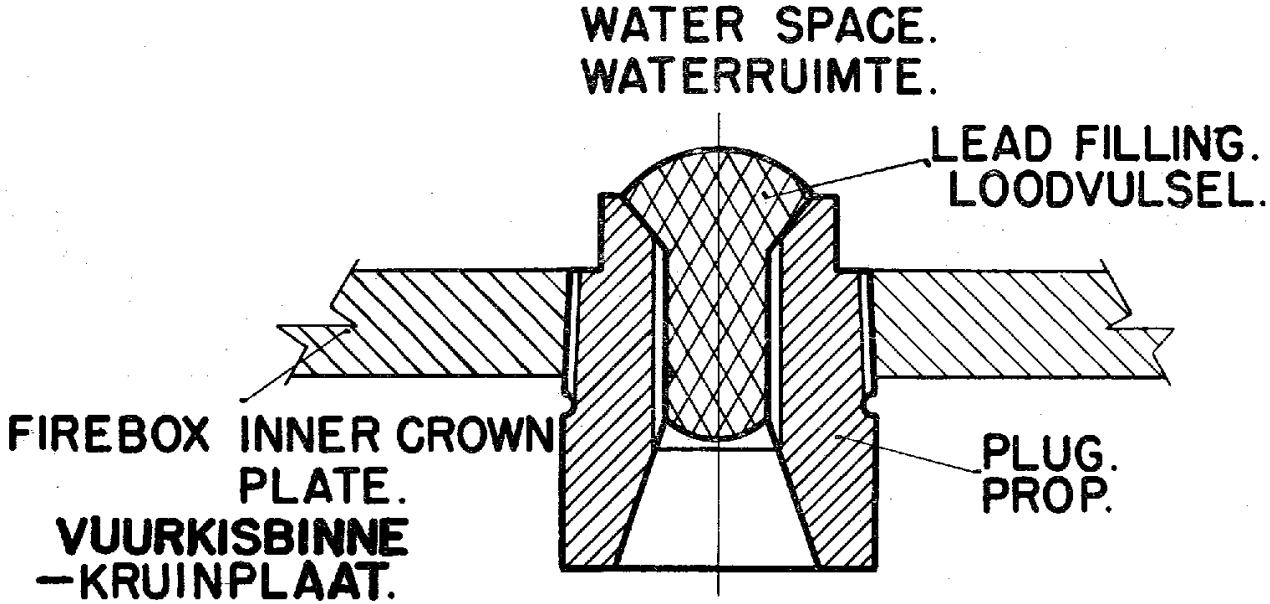
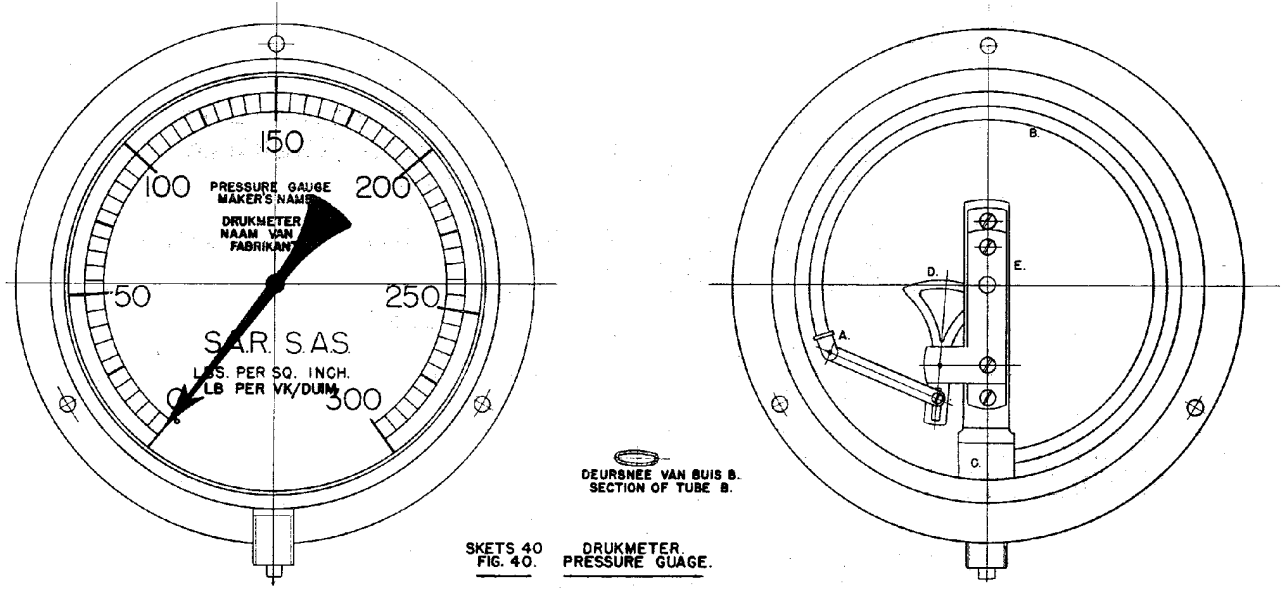


FIG.39. FUSIBLE PLUG.
SKETS.39. SMELTPROP.



SKETS 40 DRUKMETER.
FIG. 40. PRESSURE GUAGE.

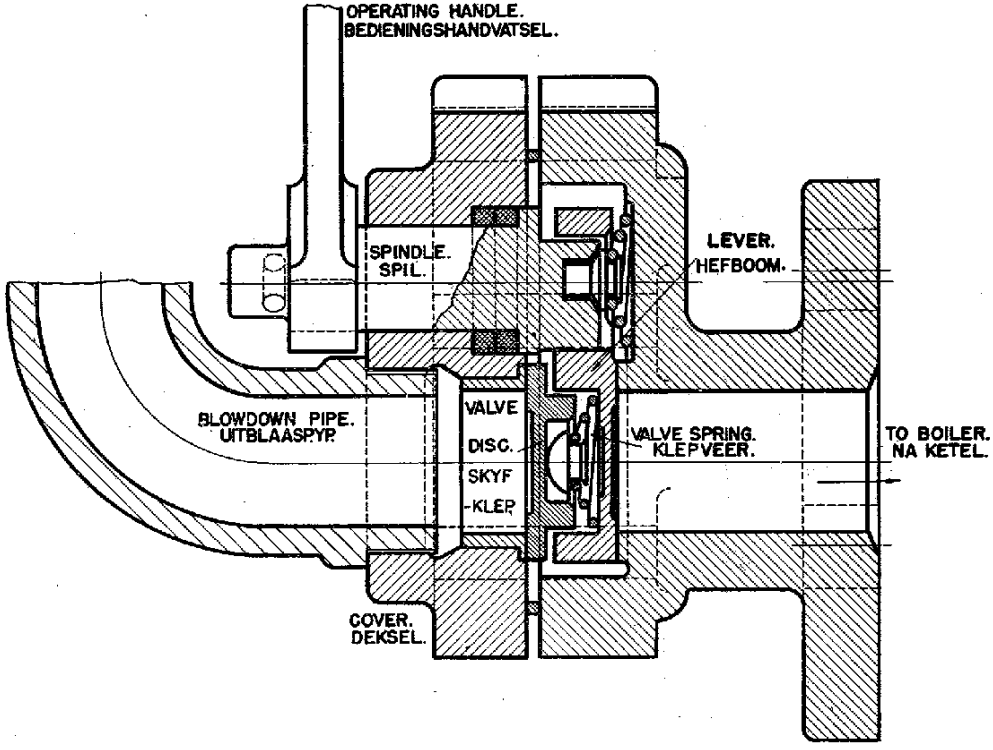


FIG. 41. „EVERLASTING" BLOWDOWN COCK.
SKETS. 41. EVERLASTING—UITBLAASKRAAN.

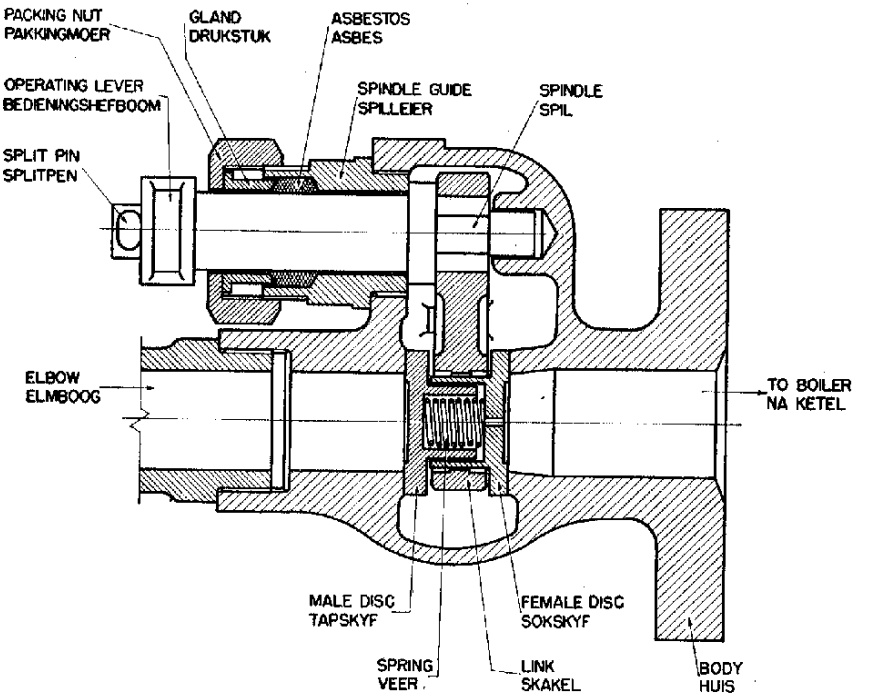
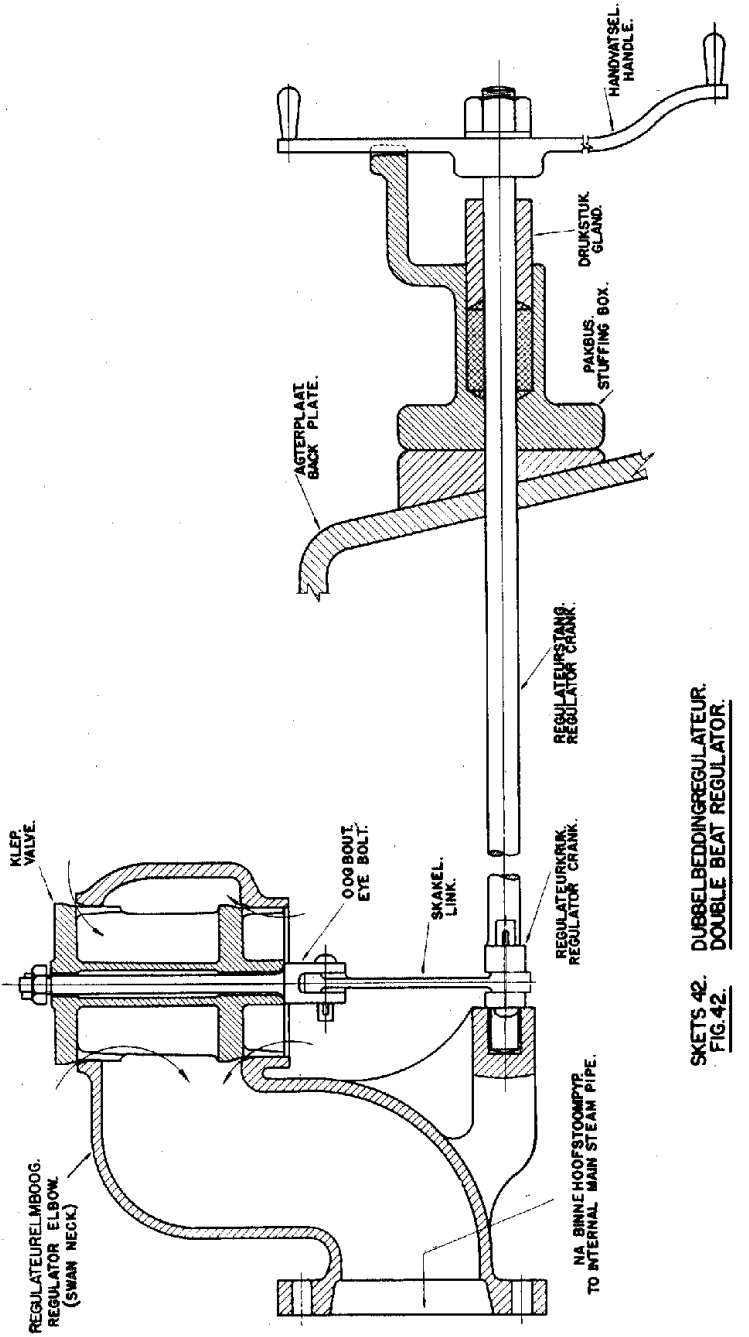


FIG. 41A.
SKETS 41A.

"HOPKINSON" BLOW-DOWN VALVE
HOPKINSON UITBLAASKLEP



SKETS 42. DUBBELBEDDINGREGULATEUR.
FIG. 42. DOUBLE BEAT REGULATOR.

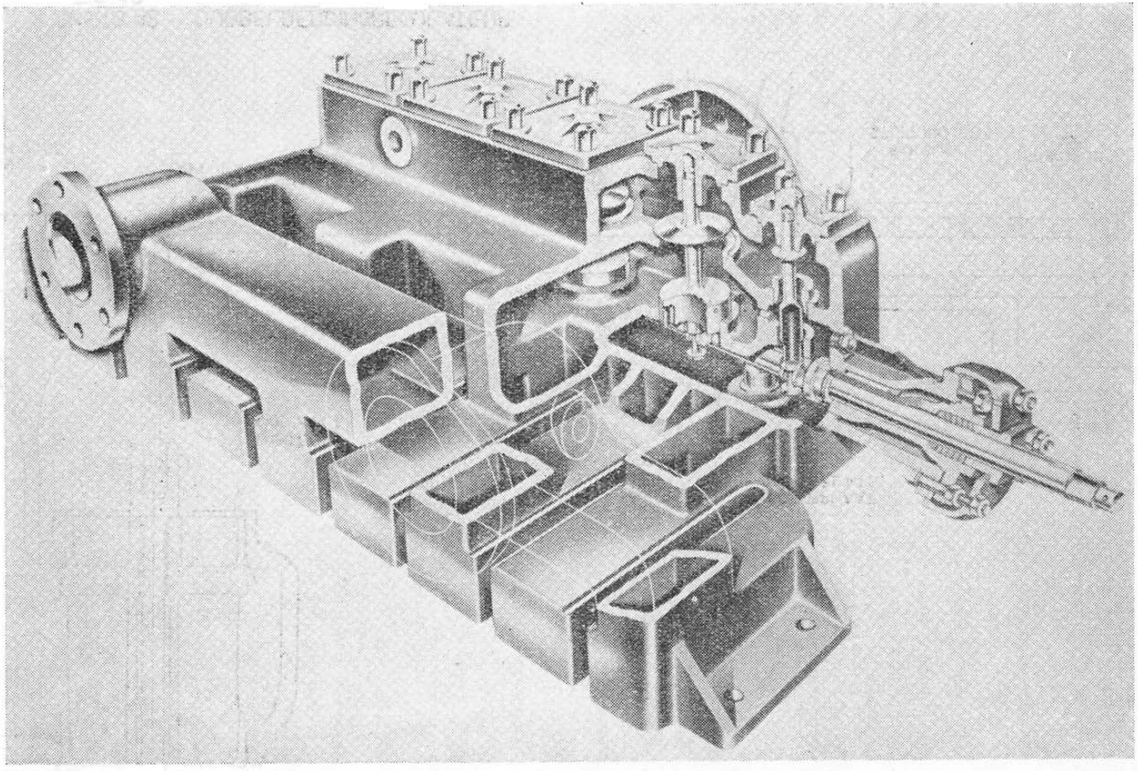
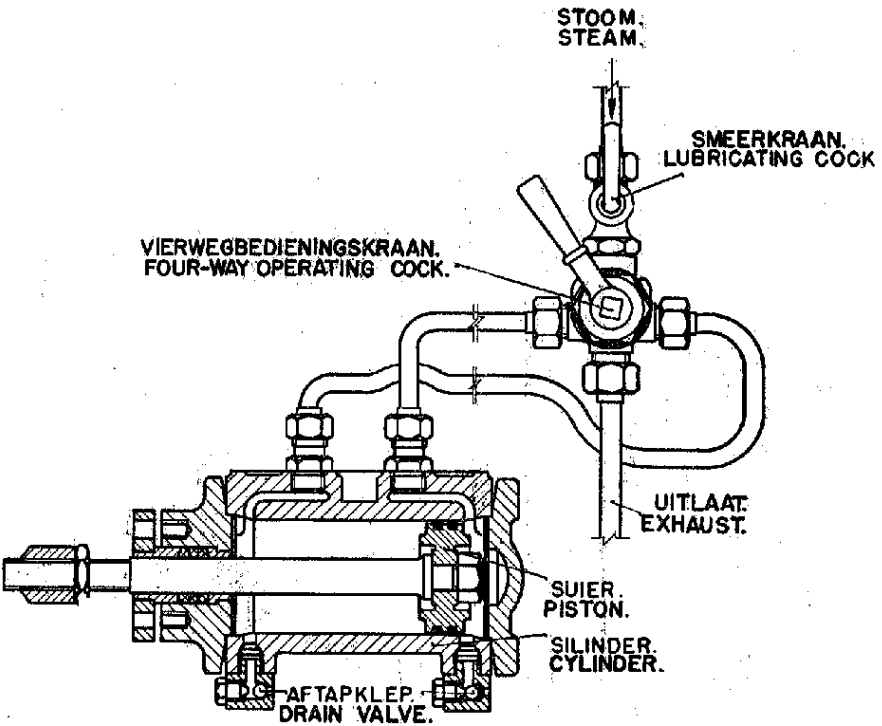


FIG. 43. MULTIPLE VALVE REGULATOR HEADER.
SKETS 43. MEERKLEPREGULATEURAFTAKKAS.



SKETS 44. FIG. 44.

ROOSTERSKUDDER EN VIERWEGBEDIENINGSKRAAN.

GRATE SHAKER STEAM CYLINDER AND FOUR WAY OPERATING COCK.

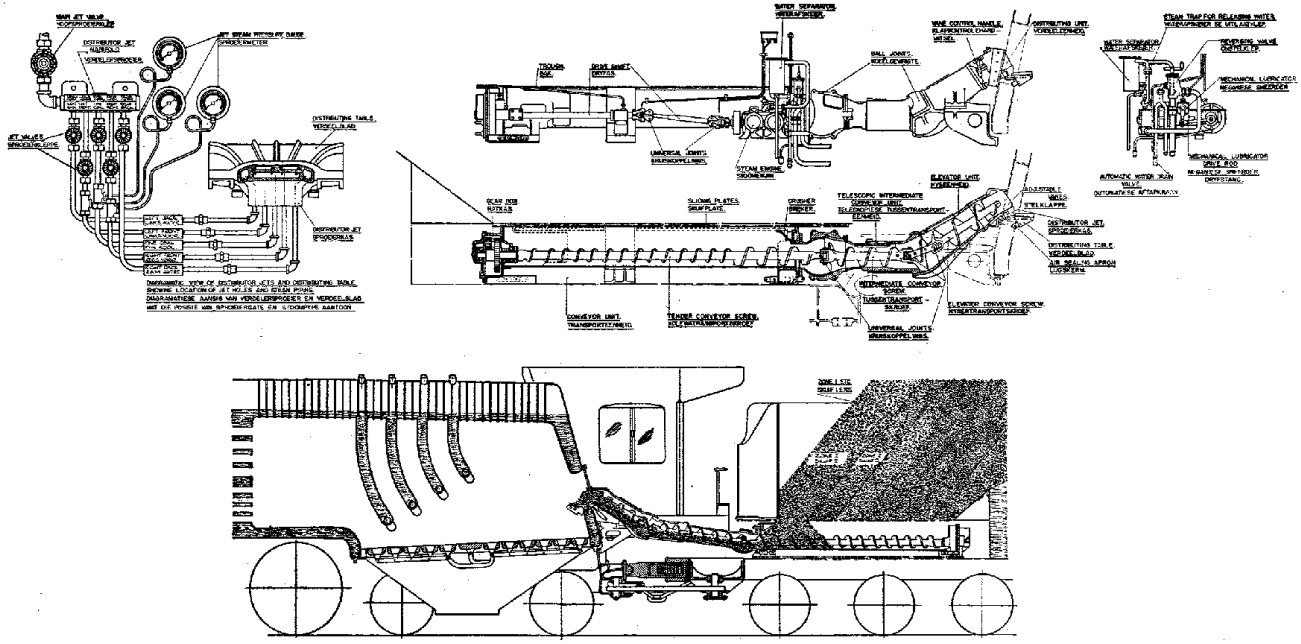


FIG. 45
SKETS 45.

ARRANGEMENT OF HT MECHANICAL STOKER
SAMESTELLING VAN MEGANIESE STOKER HT

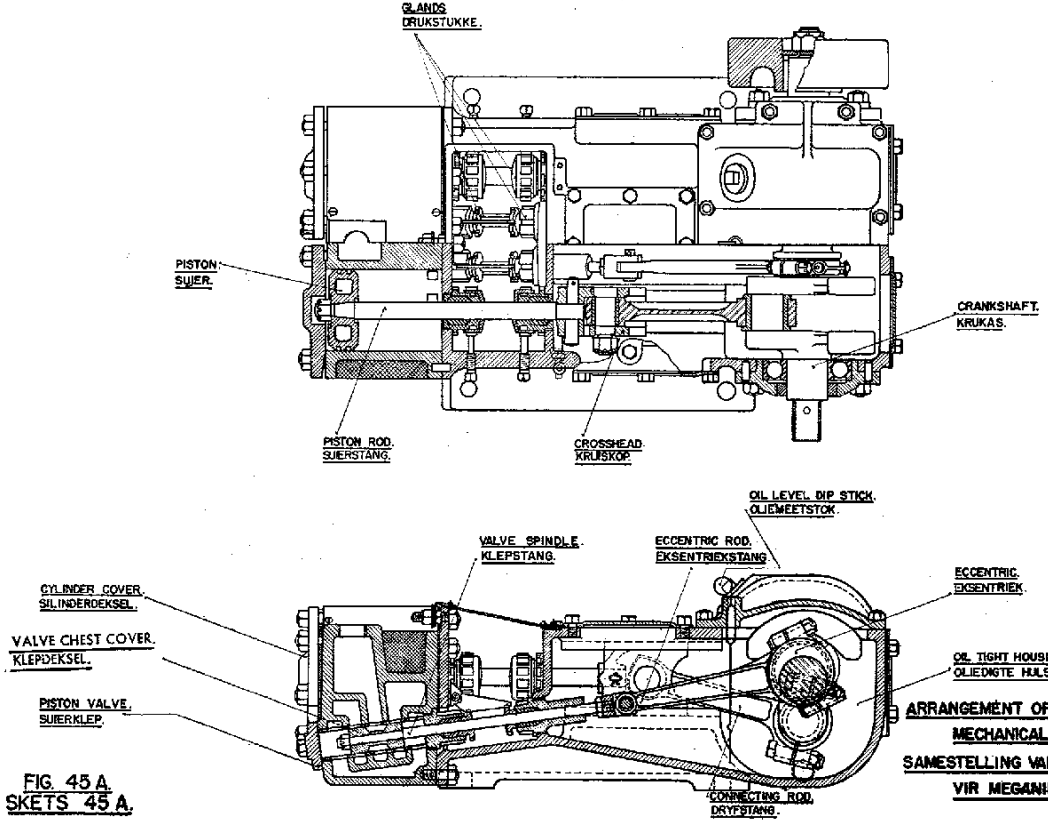
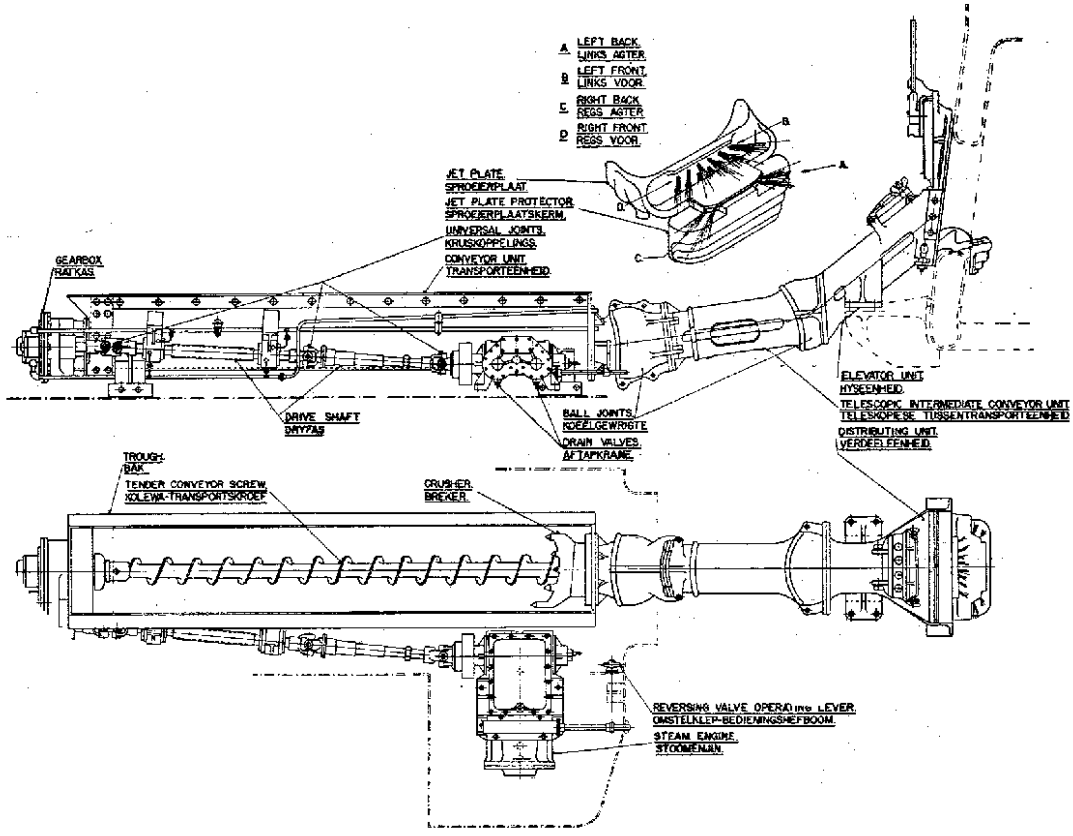


FIG. 45 A.
SKETS 45 A.

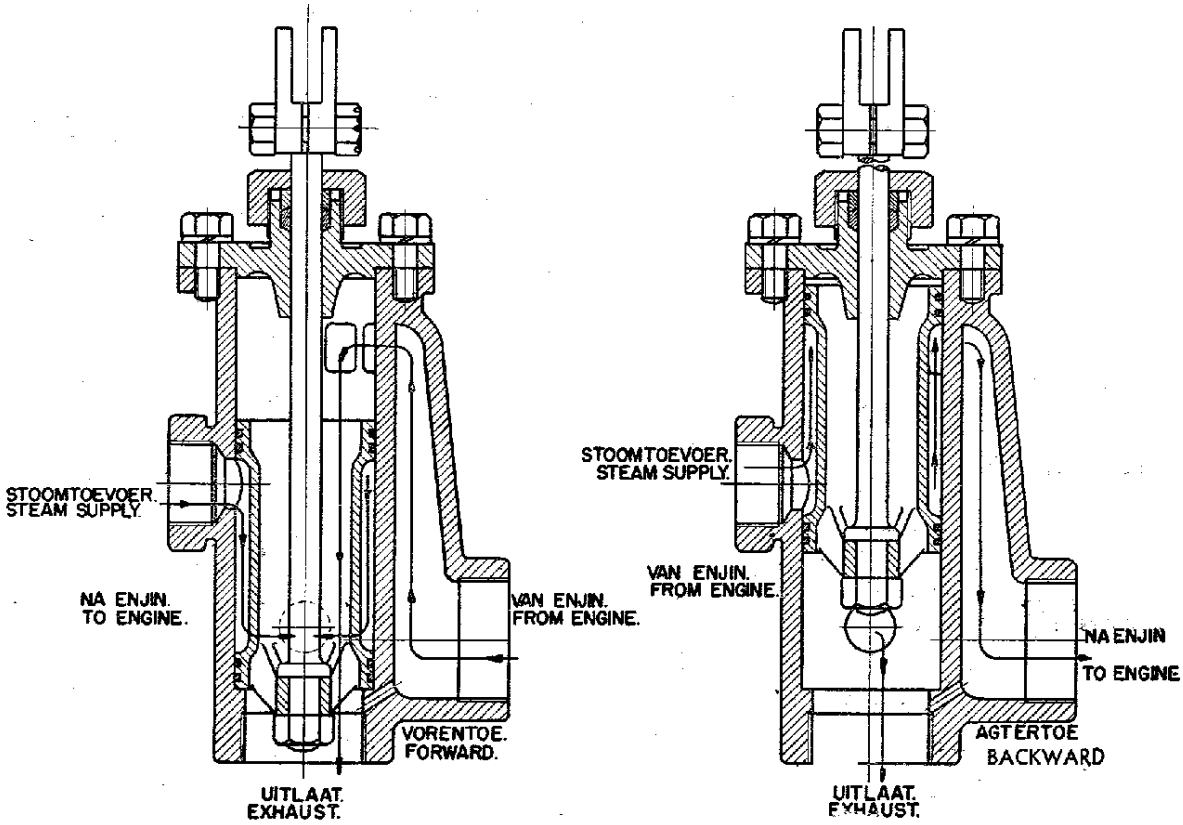
ARRANGEMENT OF STOKER ENGINE FOR MECHANICAL STOKER.

SAMESTELLING VAN STOKERENJIN VIR VIR MEGANIESE STOKER.



ARRANGEMENT OF BERKLEY MECHANICAL STOKER.
SAMESTELLING VAN BERKLEY-TIPE MEGANIESE STOKER.

FIG. 45B
SKETS 45B



SKETS 46. STOKERENJIN–OMSTELKLEP.
FIG. 46. STOKER ENGINE REVERSING VALVE.

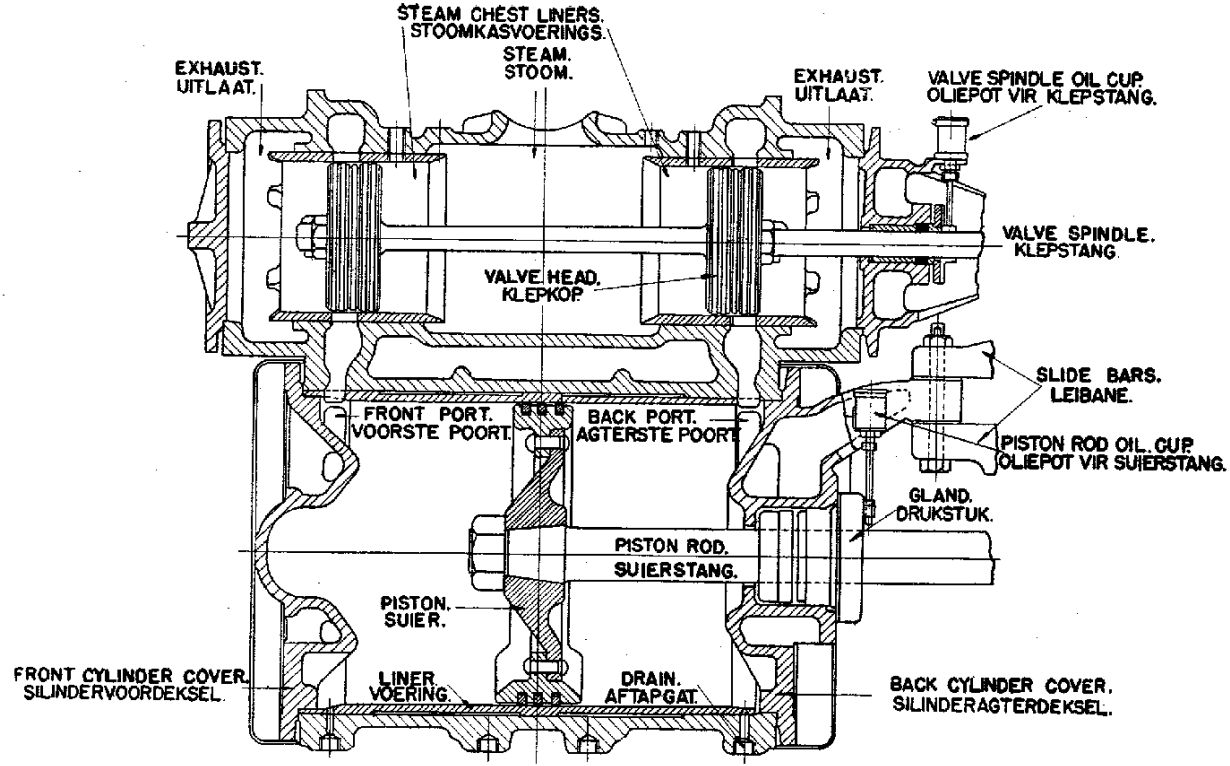
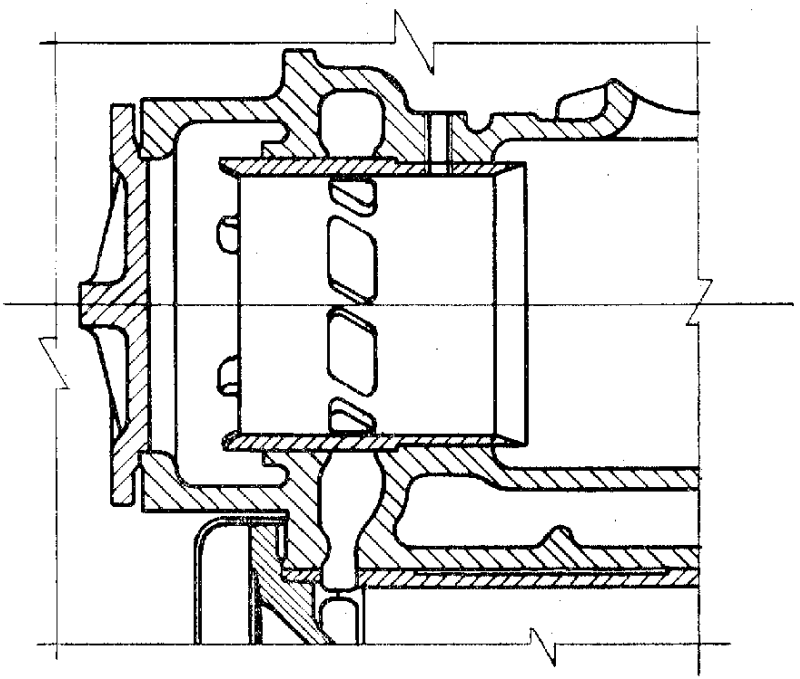


FIG 47.
SKETS. 47.

CYLINDER AND STEAM CHEST. (INSIDE ADMISSION.)
SILINDER EN STOOMKAS. (BINNETOELAAT.)



POORT.
PORT.

SKETS 48-STOOMKASVOERING.
FIG. 48– STEAM CHEST LINER.

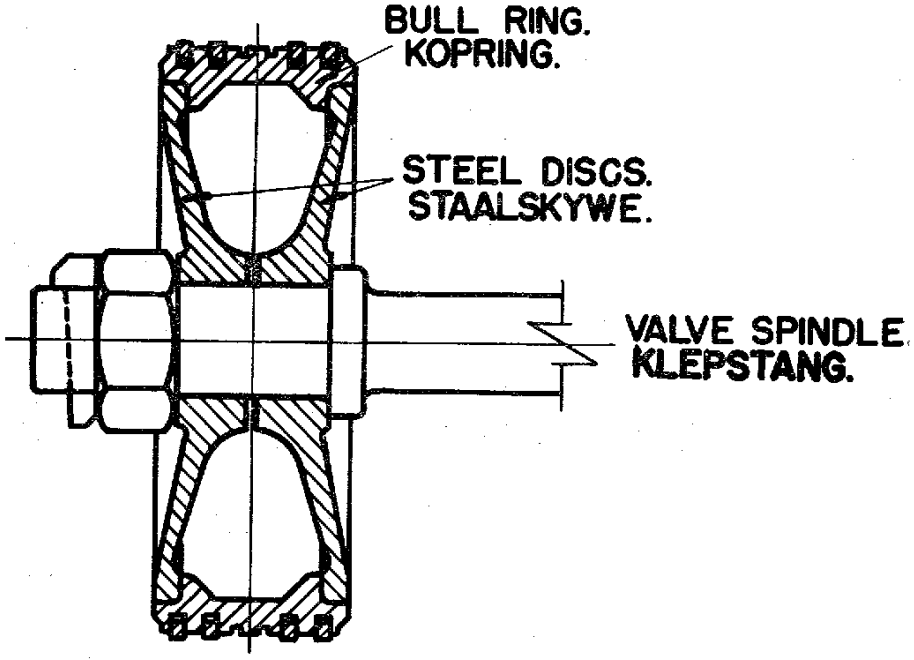
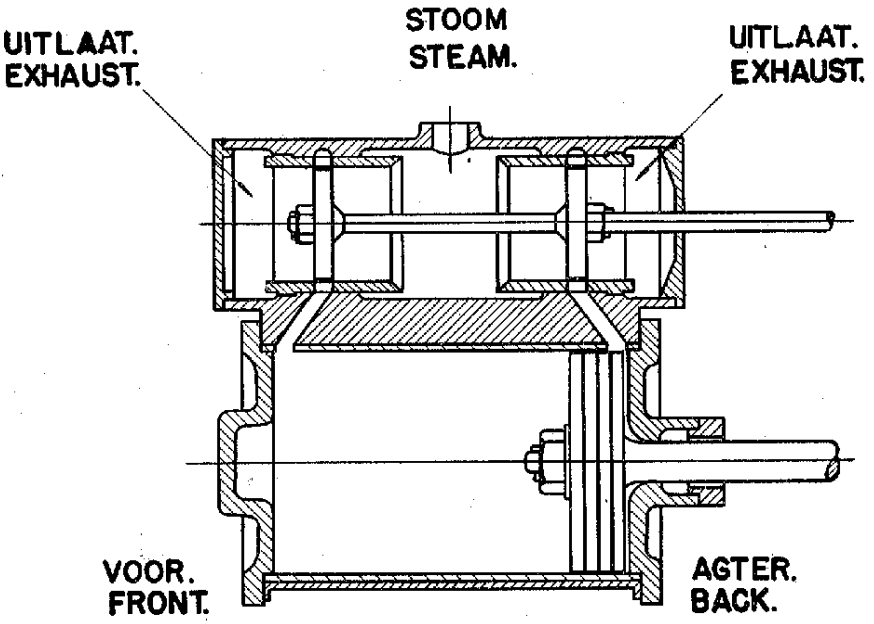


FIG.49.
SKETS.49.

BULL RING TYPE VALVE HEAD.
KOPRINGTIPE KLEPKOP



SKETS 50 – ELEMENTÊRE SILINDER EN STOOMKAS.

FIG. 50 – ELEMENTARY CYLINDER AND STEAM CHEST.

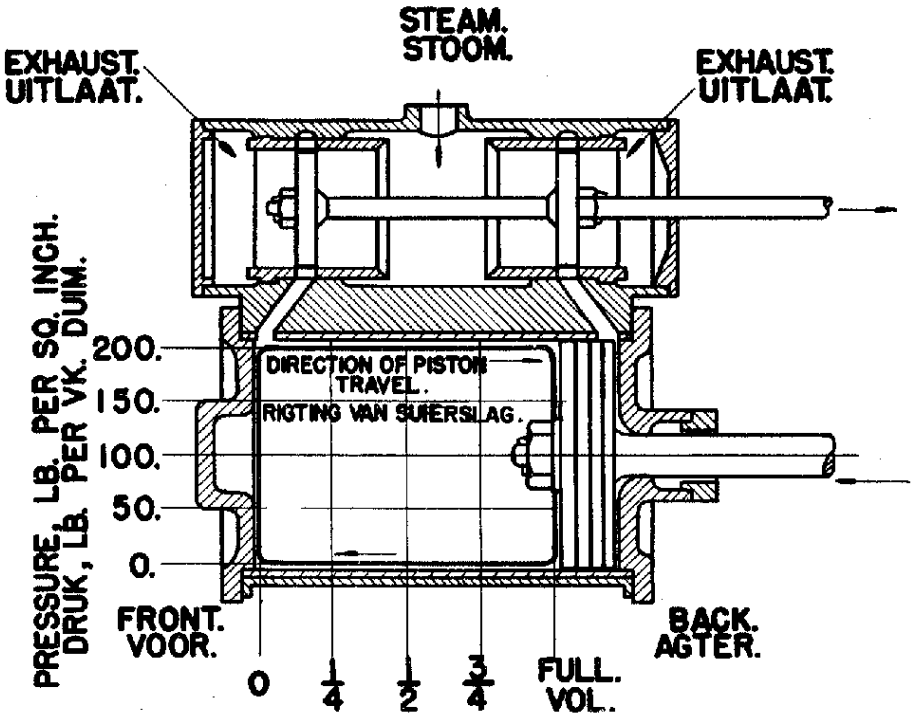
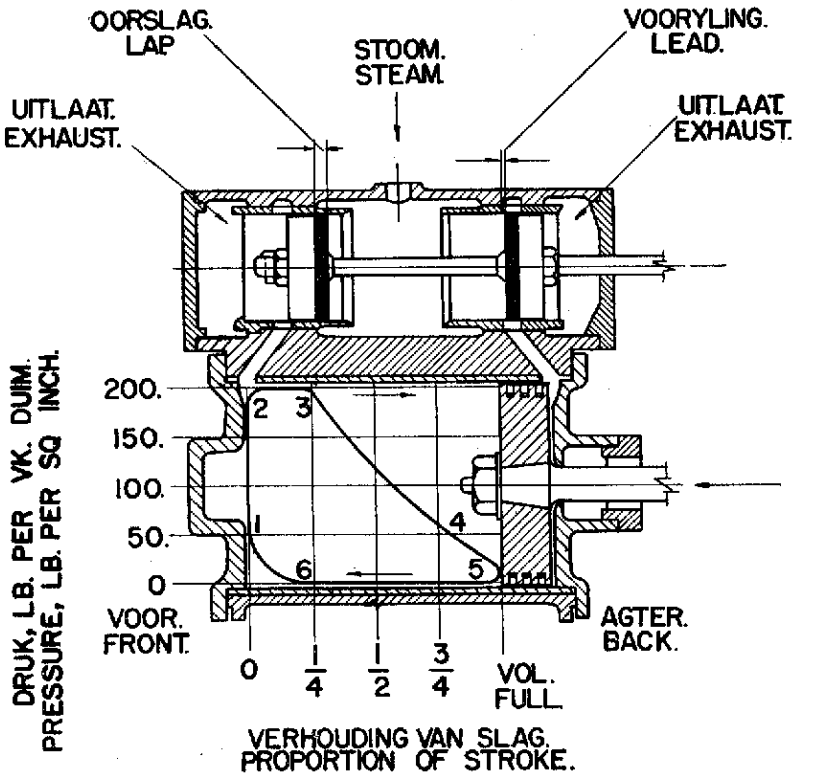


FIG. 51. ELEMENTARY CYLINDER AND STEAM CHEST.

SKETS 51. ELEMENTÊRE SILINDER EN STOOMKAS.



SKETS 52. SILINDER EN STOOMKAS MET OORSLAG EN VOORYLING AAN KLEP.
FIG.52. CYLINDER AND STEAM CHEST WITH LAP AND LEAD ON VALVE.

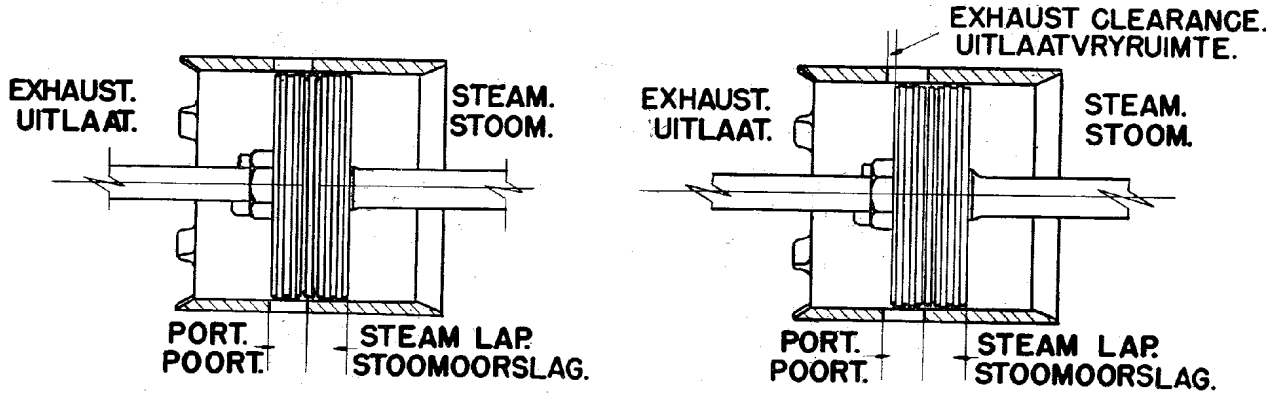
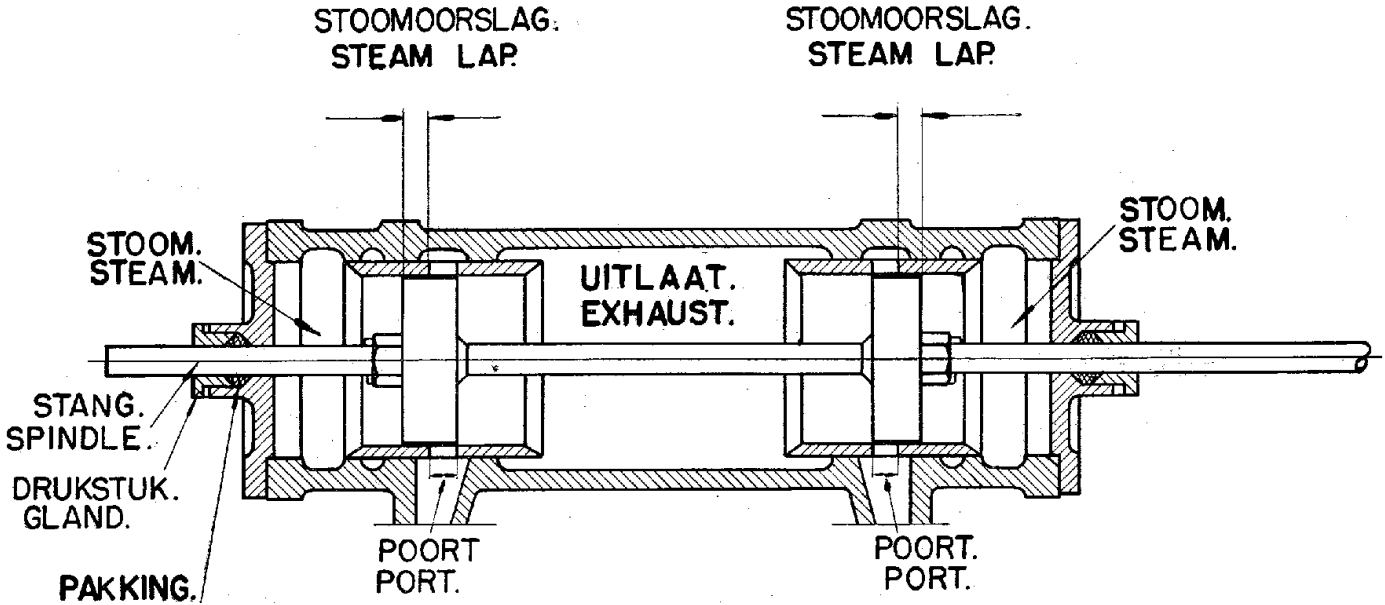


FIG. 53.
SKETS. 53.

KLEP SONDER UITLAATVRYRUIMTE EN EEN DAARMEE.
VALVE WITHOUT EXHAUST CLEARANCE AND ONE WITH.



SKETS 54— BUITETOELAAT— SUIERKLEP.
FIG. 54—OUTSIDE ADMISSION PISTON VALVE.

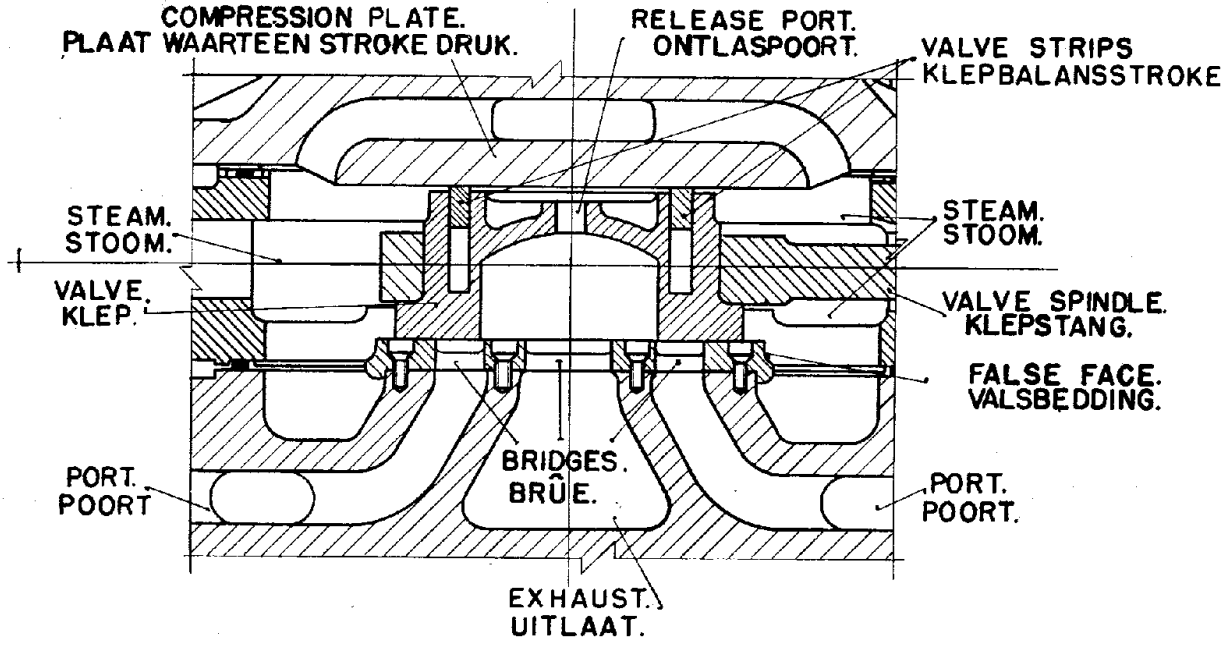
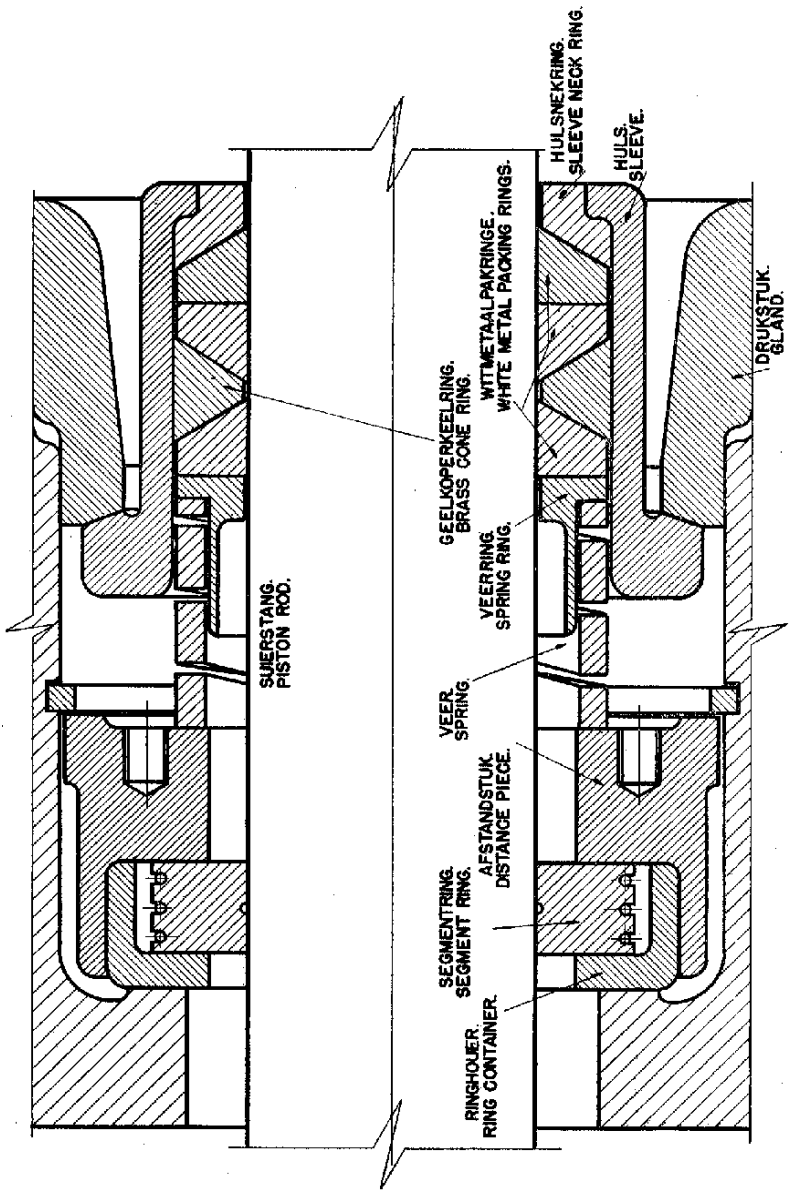


FIG. 55. SLIDE VALVE.
SKETS 55. SKUIFKLEP.



SKETS 56.
FIG. 56.

SUIERSTANGMETAALPAKKING.
PISTON ROD METALLIC PACKING.

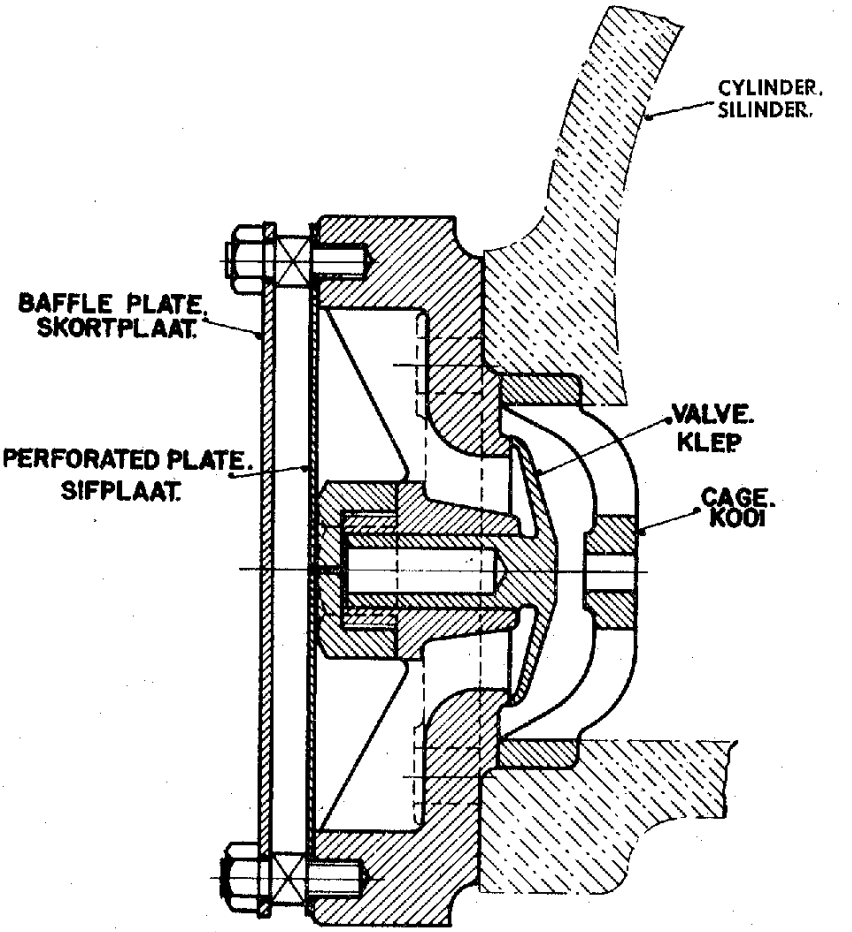
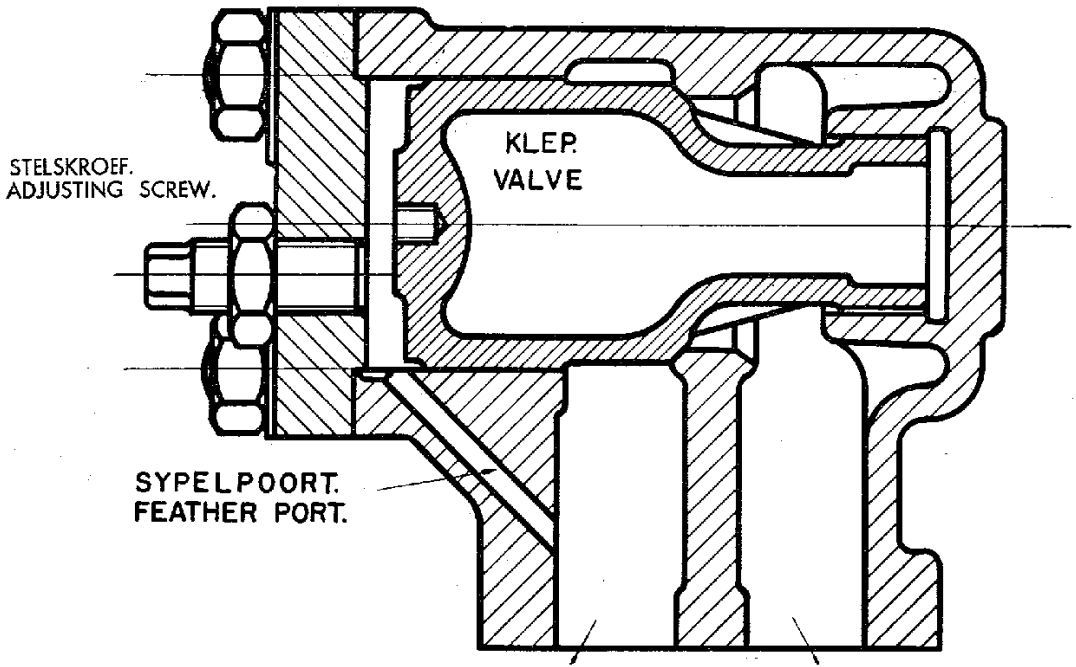


FIG. 57. SNIFTING VALVE.
SKETS 57 SNUIFKLEP



SKETS 58. OMLOOPKLEP.
FIG. 58. BYE-PASS VALVE.

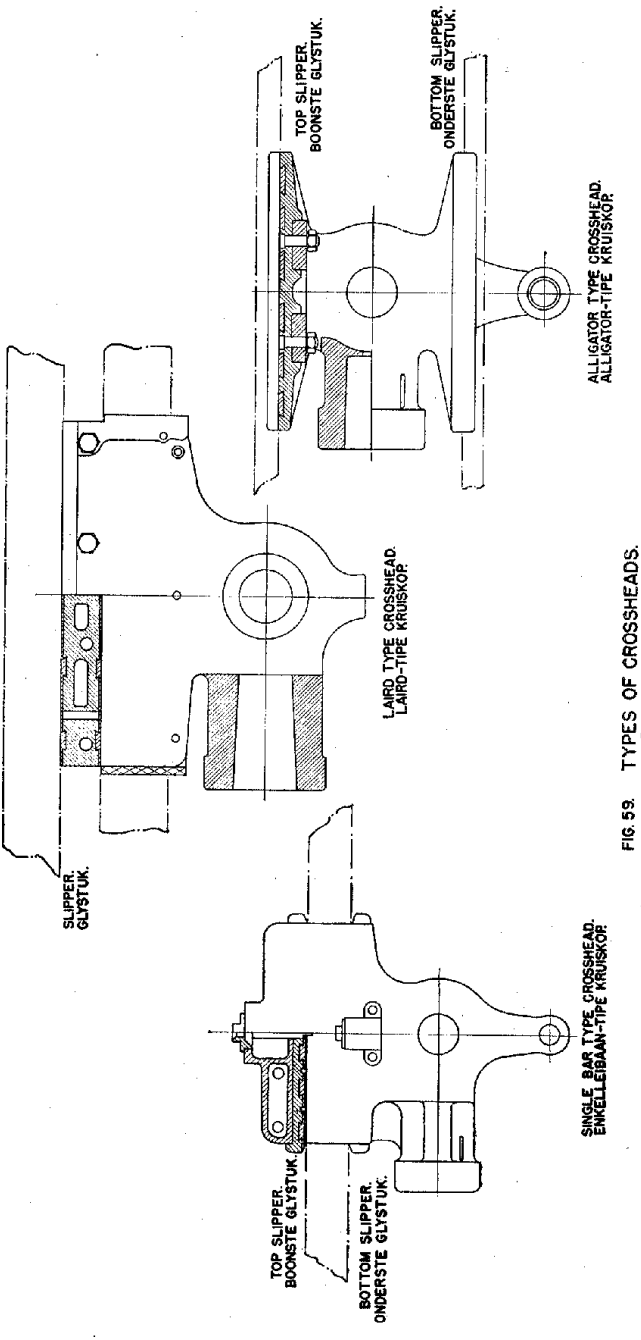
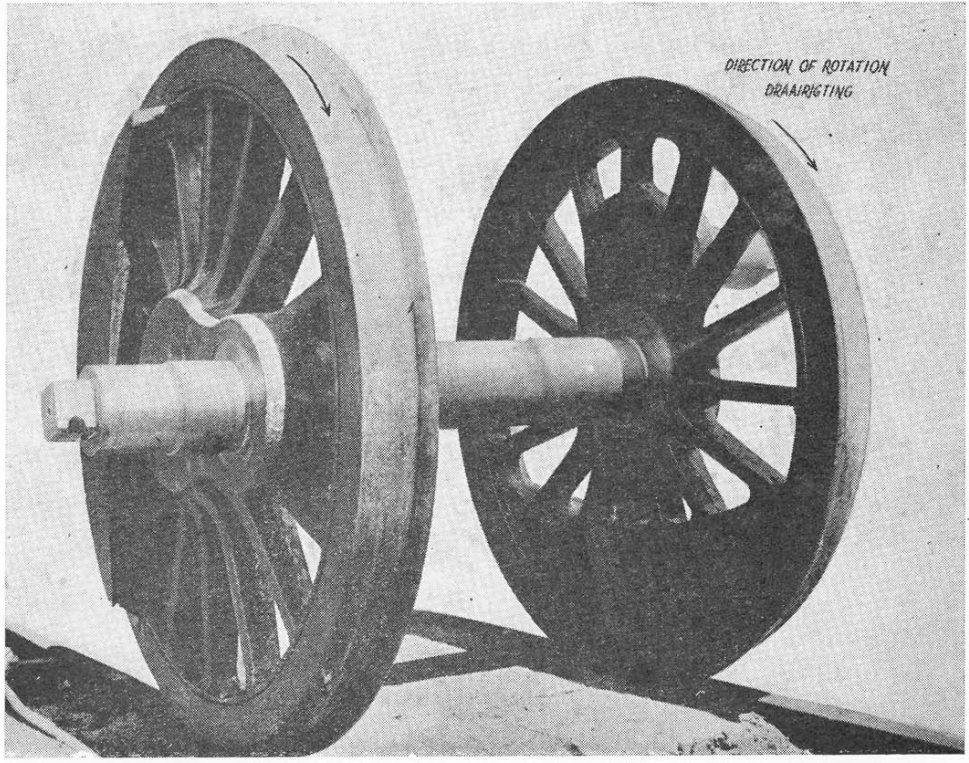


FIG. 59. TYPES OF CROSSHEADS.
SKETS 59. KRUISKOP-TIPES.



SKETS 60. RELATIEWE STANDE VAN KRUKKE AAN KOPPELWIELE.
FIG. 60. RELATVE POSITION OF CRANKS ON COUPLED WHEELS.

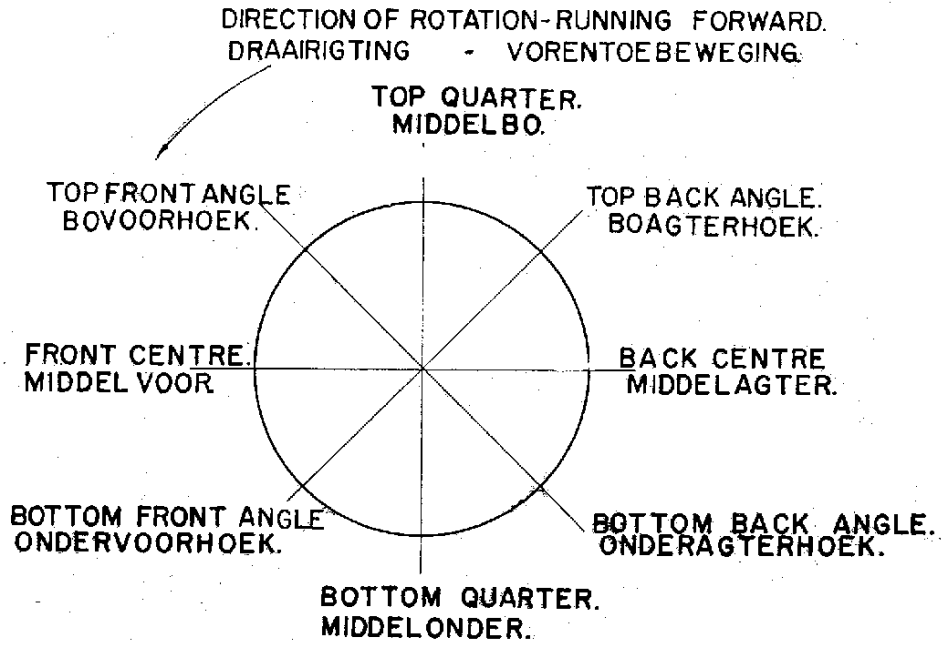
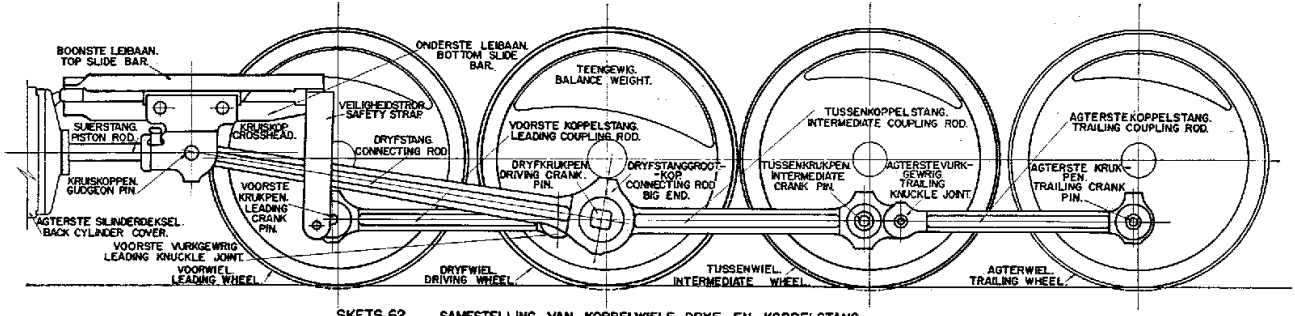


FIG. 61 - NAMES OF VARIOUS CRANK POSITIONS.
SKETS. 61 - NAME VAN VERSKILLENDE KRUKSTANDE.

WHEEL SEEN FROM L.H. SIDE OF LOCOMOTIVE.
WIEL VAN LINKERKANT VAN LOKOMOTIEF GESIEN.



SKETS 62 SAMESTELLING VAN KOPPELWIELE, DRYF EN KOPPELSTANG.
FIG. 62 ARRANGEMENT OF COUPLED WHEELS, CONNECTING AND COUPLING RODS.

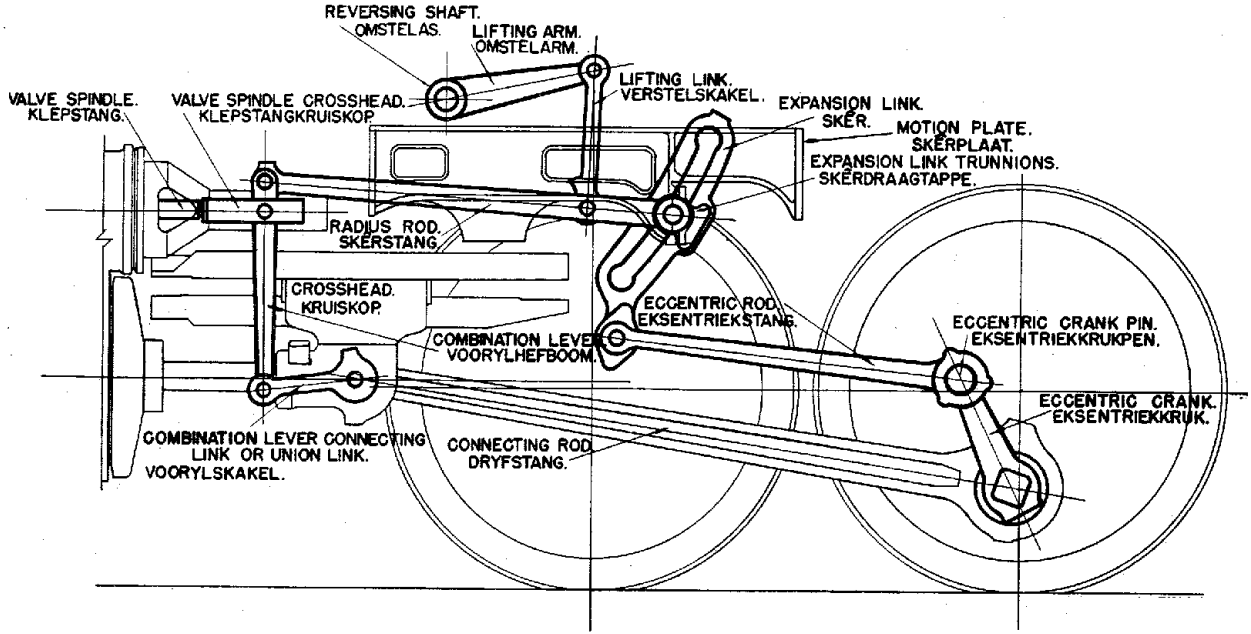
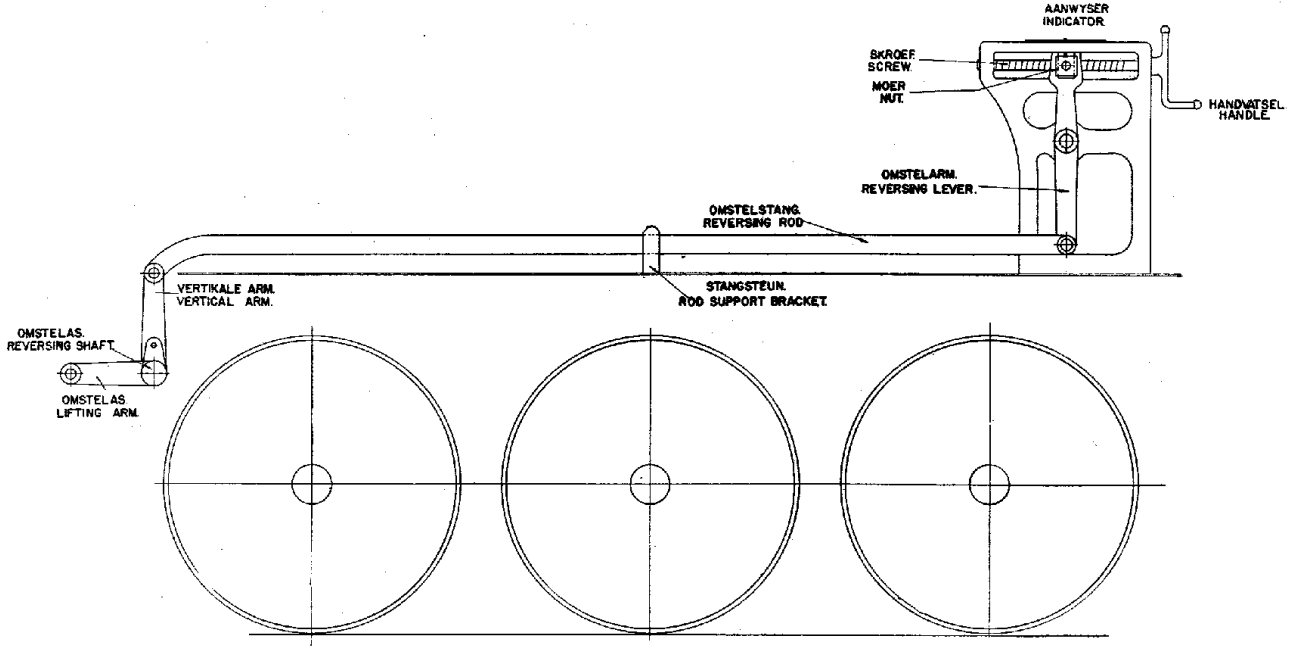


FIG. 63. WALSCHAERTS VALVE GEAR.
SKETS. 63. WALSCHAERTS- KLEPWERK.



SKETS 64 SKROEFOMSTELWERK
FIG 64 SCREW REVERSING GEAR

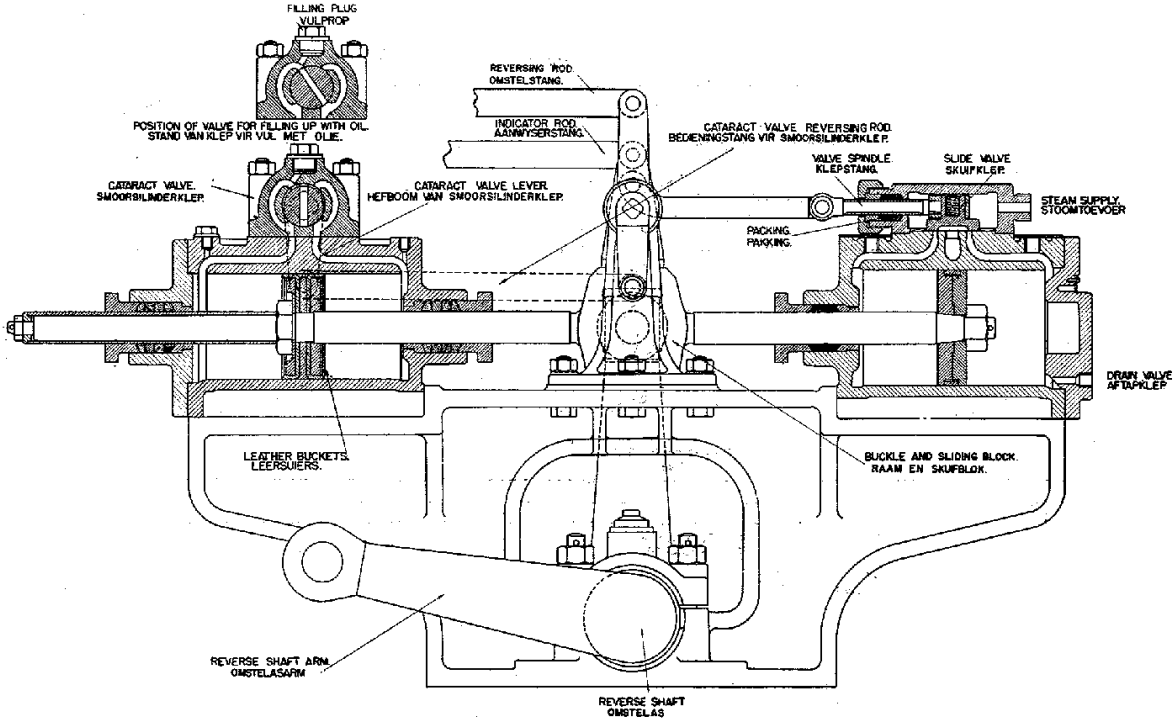
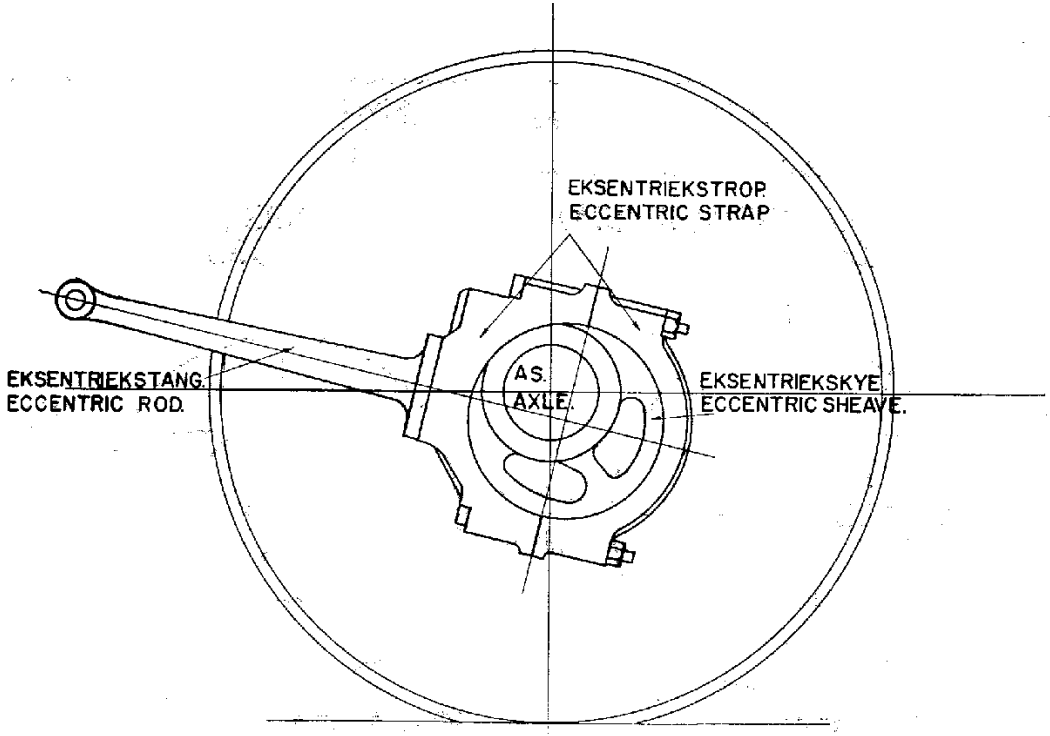


FIG.65.
SKETS 65.

STEAM REVERSING ENGINE
OMSTELENJIN



SKETS 66. EKSENTRIEK.
FIG 66. ECCENTRIC.

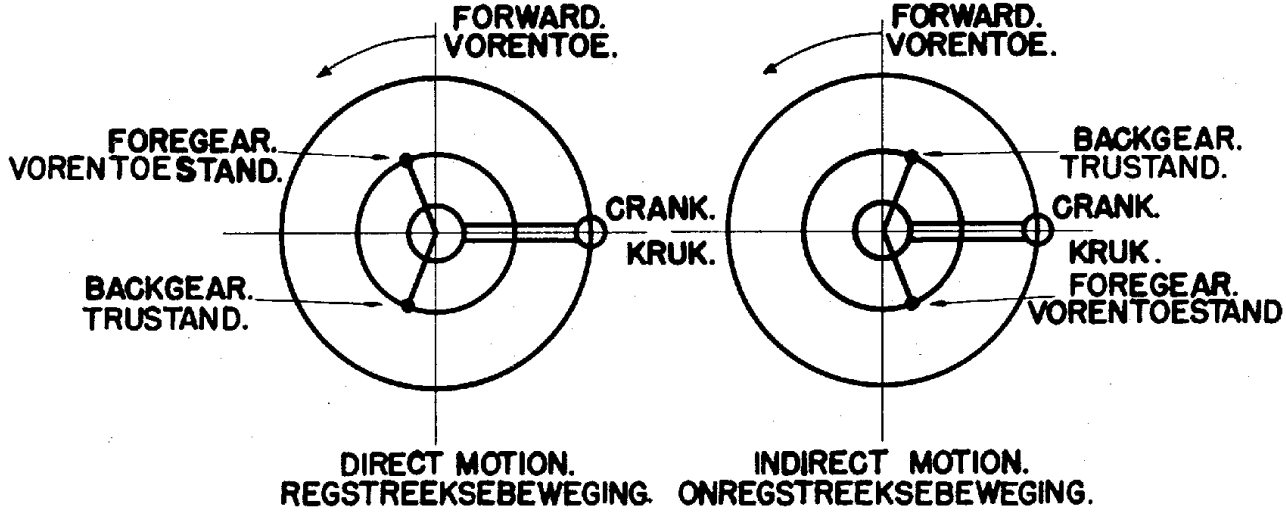
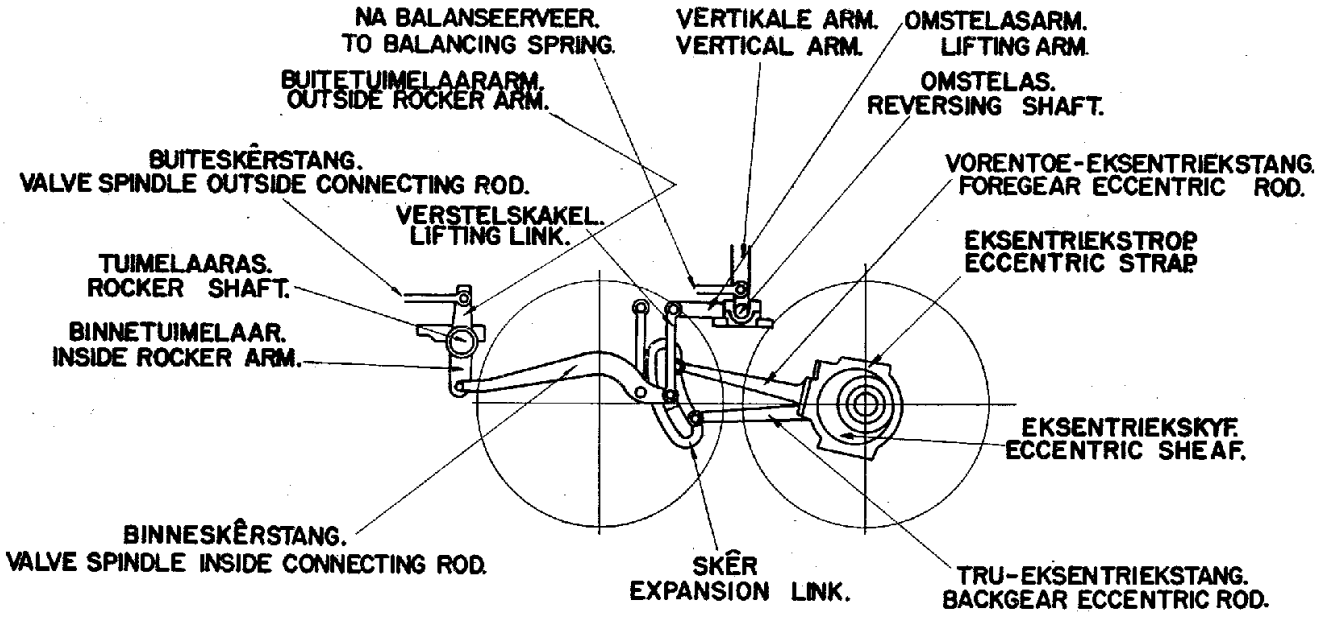


FIG. 67. POSITIONS OF ECCENTRICS.
SKETS 67. STANDE VAN EKSENTRIEKKRUK.



SKETS 68. STEPHENSON - KLEPWERK.
FIG. 68. STEPHENSON LINK MOTION.

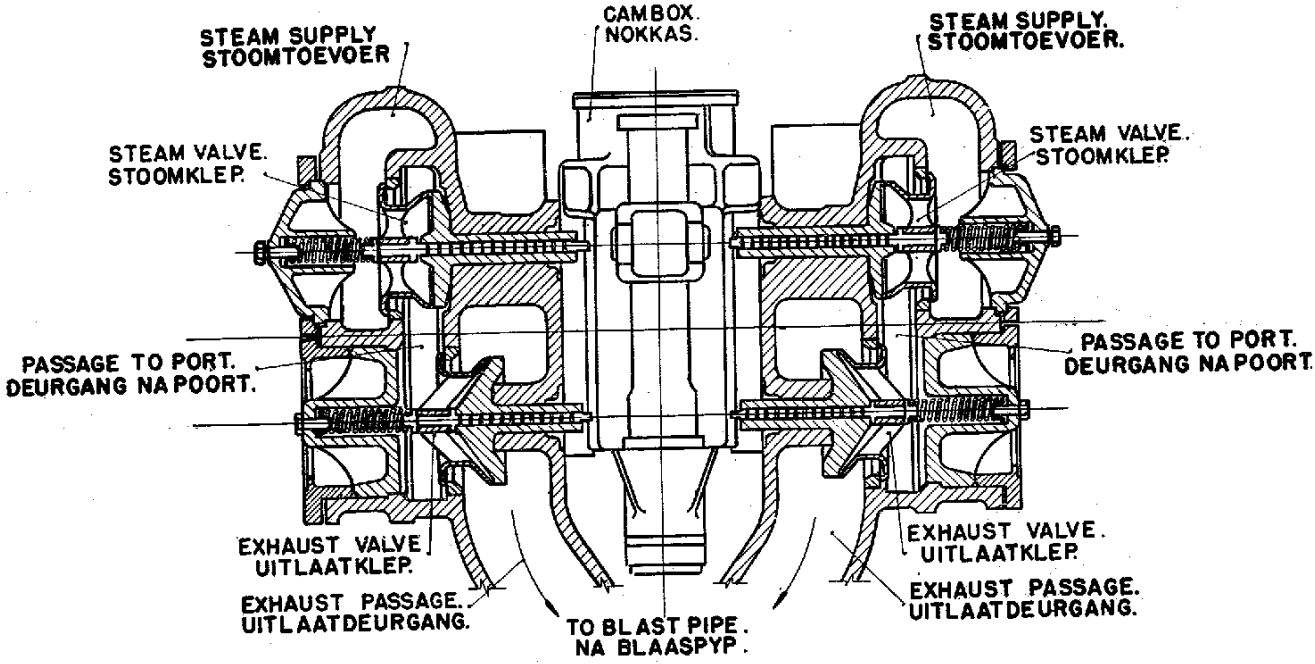
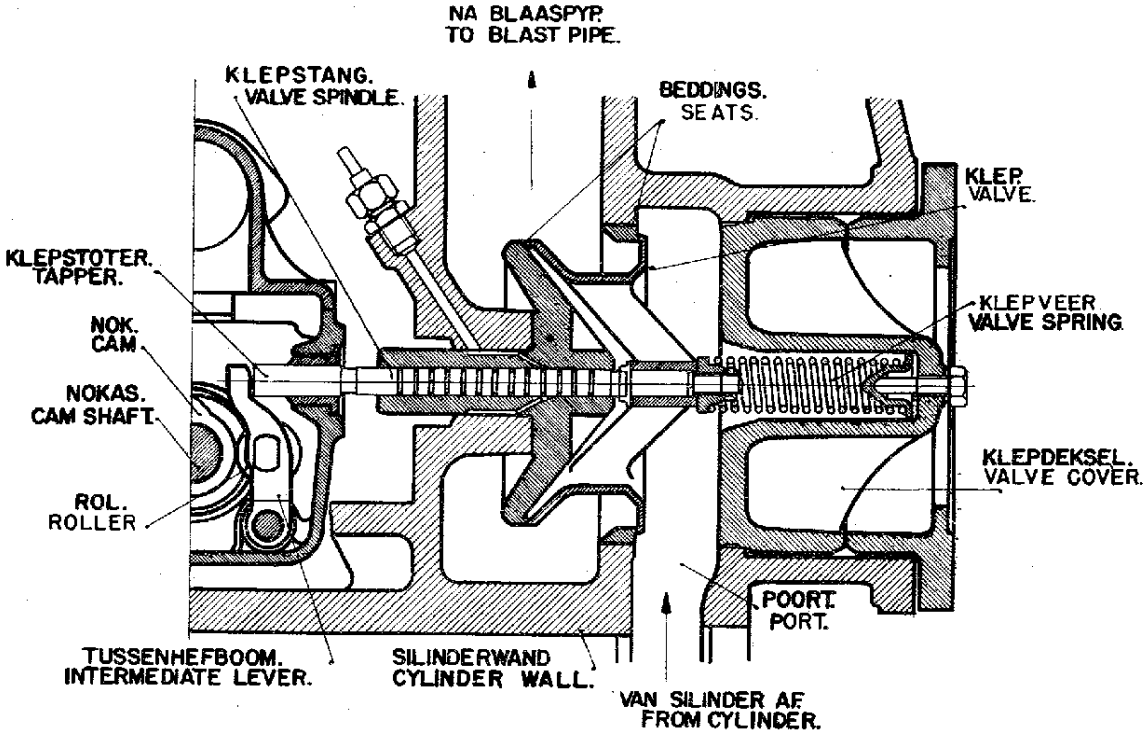


FIG 69. ARRANGEMENT OF VALVES—"R.C." VALVE GEAR.
SKETS 69. SAMESTELLING VAN KLEPPE—R.C.- KLEPWERK.



SKETS 70. UITLAATKLEP EN NOKKAS – R.C. KLEPWERK.
FIG. 70. EXHAUST VALVE AND CAM BOX – "R.C." VALVE GEAR.

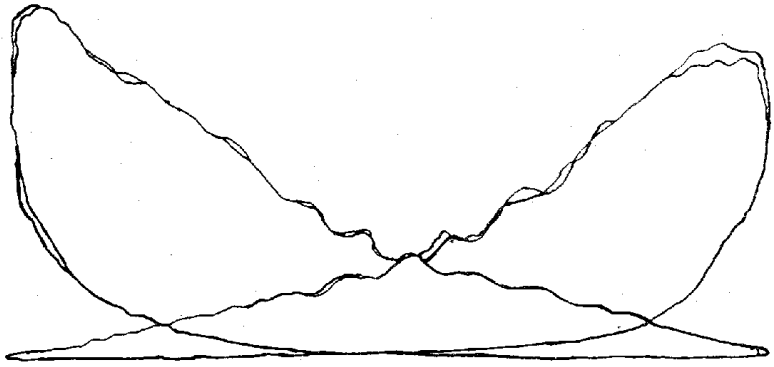
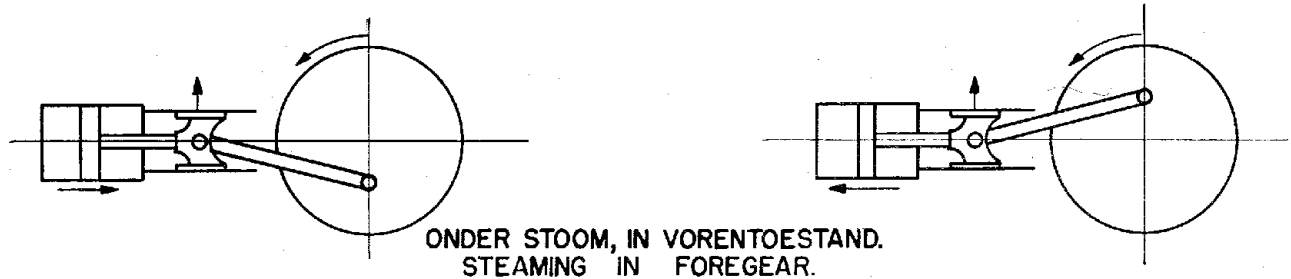
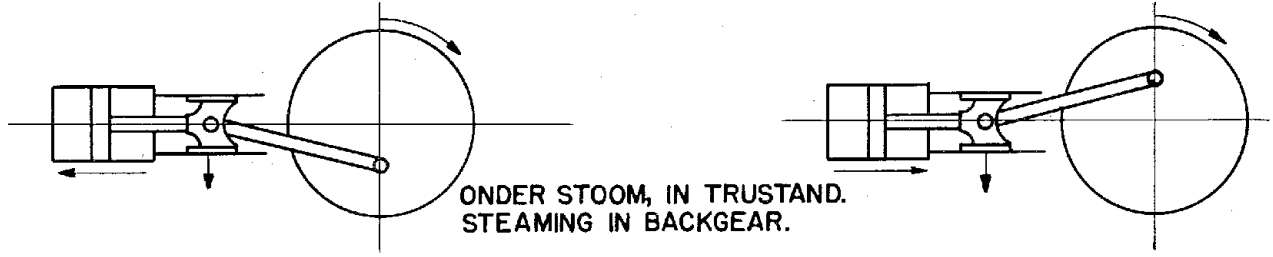


FIG. 71 – ACTUAL INDICATOR DIAGRAM – 25 % CUT OFF.
SKETS 71 – WERKLIKE INDIKATEURDIAGRAM – 25 % AFSLUITING.



ONDER STOOM, IN VORENTOESTAND.
STEAMING IN FOREGEAR.



ONDER STOOM, IN TRUSTAND.
STEAMING IN BACKGEAR.

SKETS 72. RIGTINGS VAN KRUISKOPSTOOT.
FIG. 72 DIRECTIONS OF CROSSHEAD THRUST.

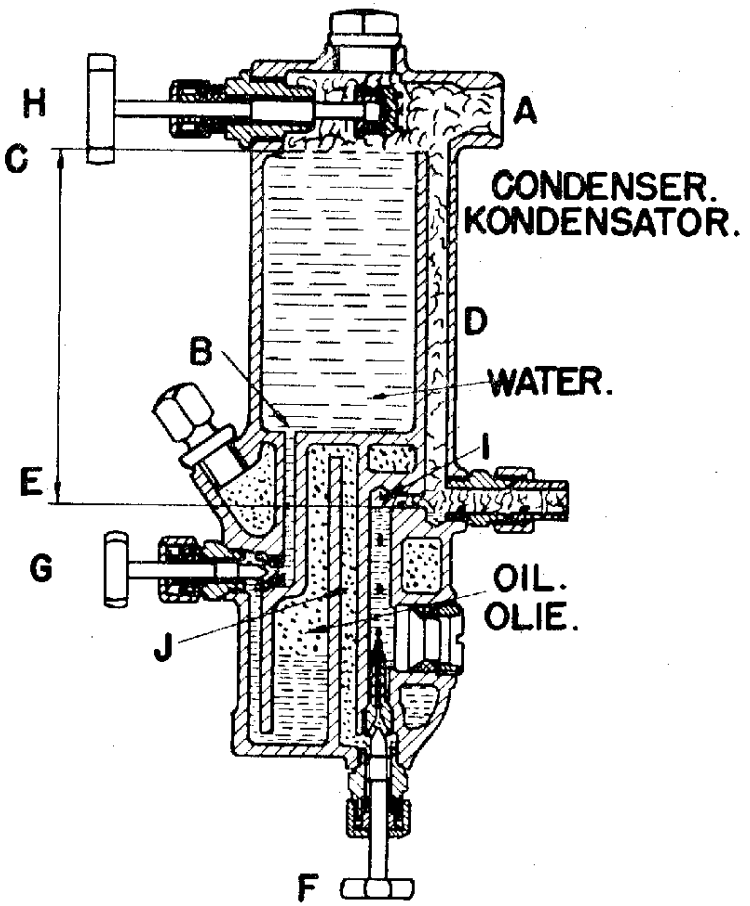
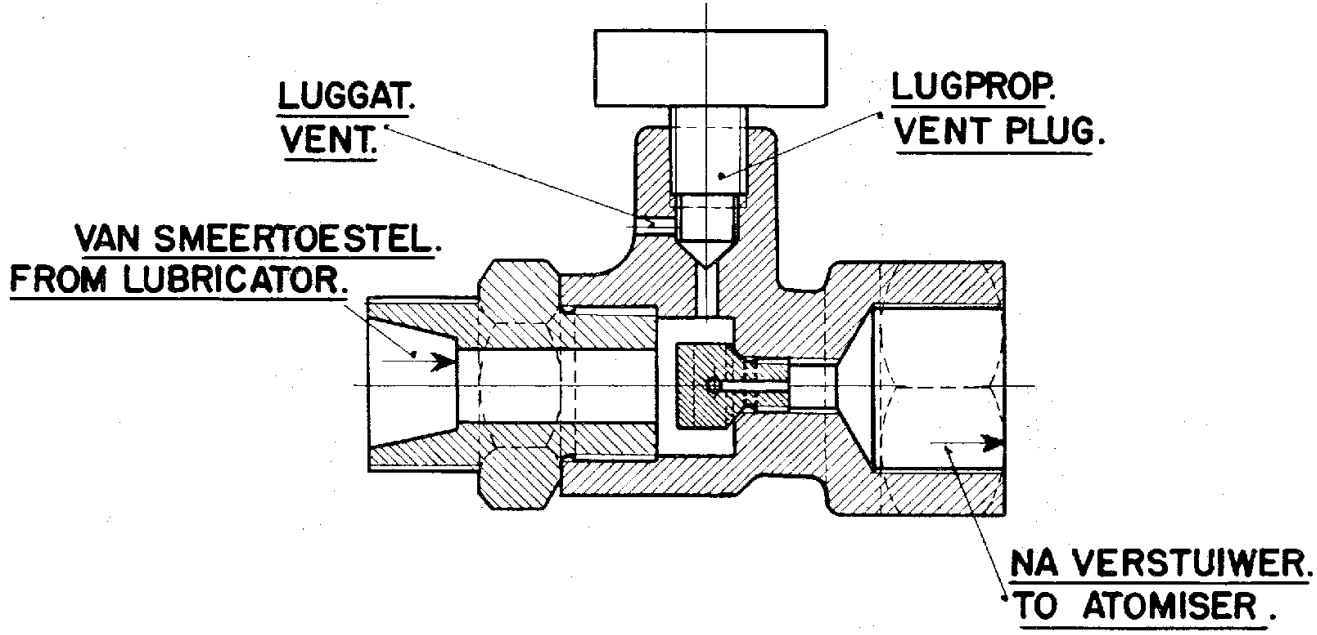


FIG. 73. HYDROSTATIC LUBRICATOR.
SKETS 73. HIDROSTATIESE SMEERTOESTEL.



SKETS. FIG. 74. SMOORKLEP. CHOKE VALVE.

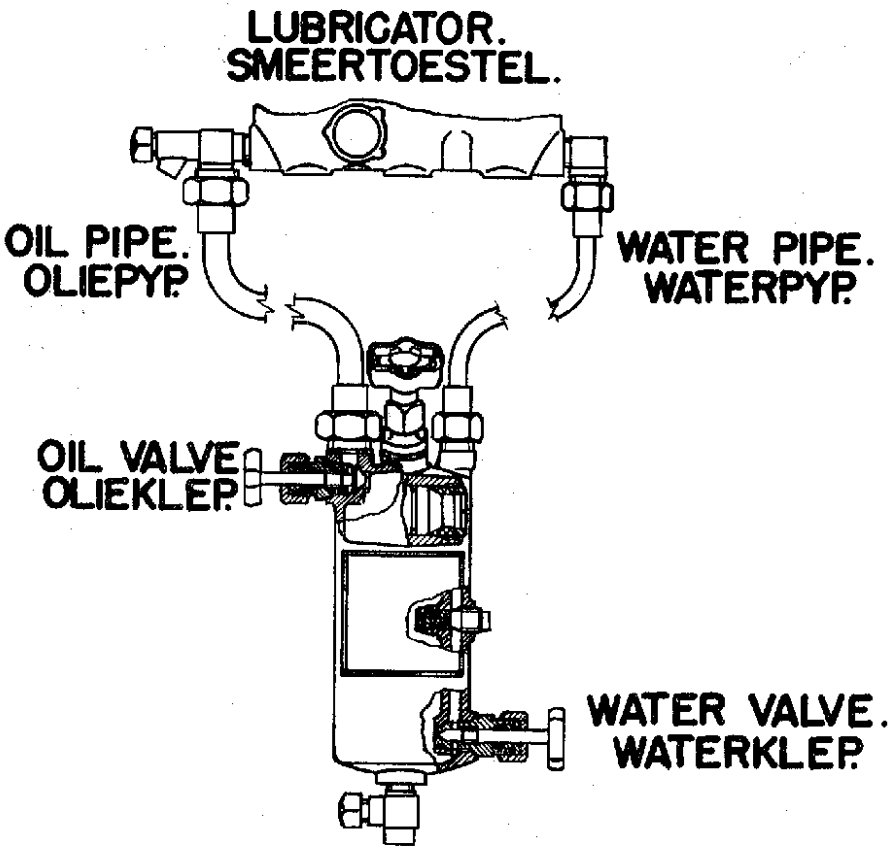
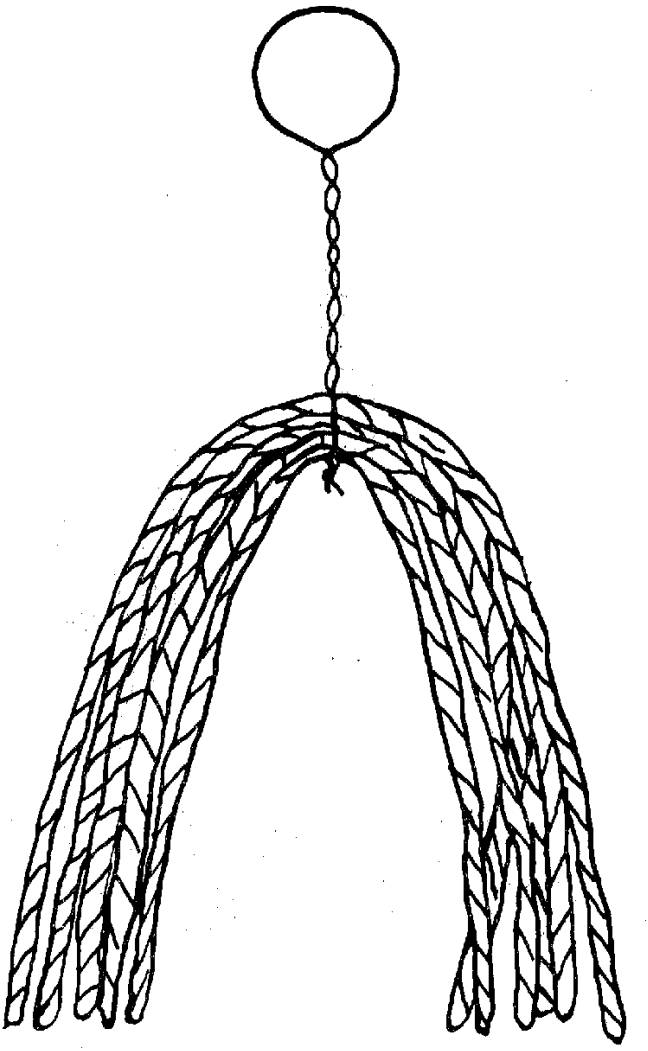


FIG. 75 TRANSFER FILLER.
SKETS 75. OMRUILOPVULLER.



SKETS 76. – VERDEELPIT.
FIG. 76. – TAIL TRIMMING.

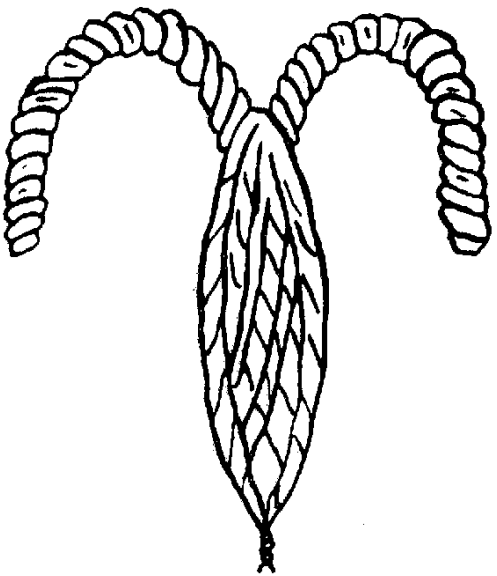
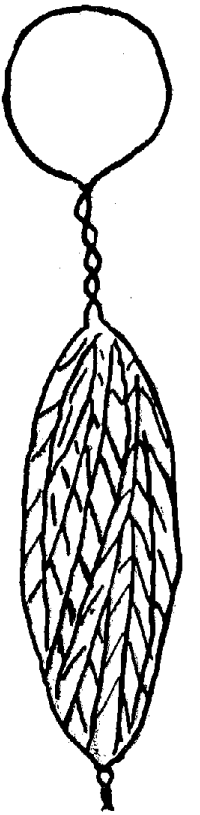


FIG 77. HORN TRIMMING.
SKETS 77. ANKERPIT.



SKETS 78 - PROPPIT.

FIG. 78 — PLUG TRIMMING.

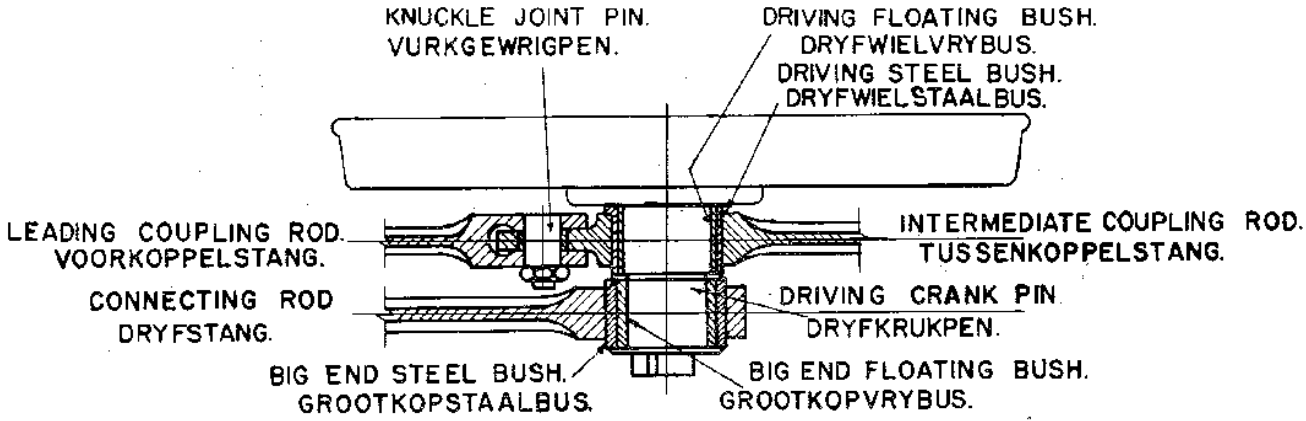
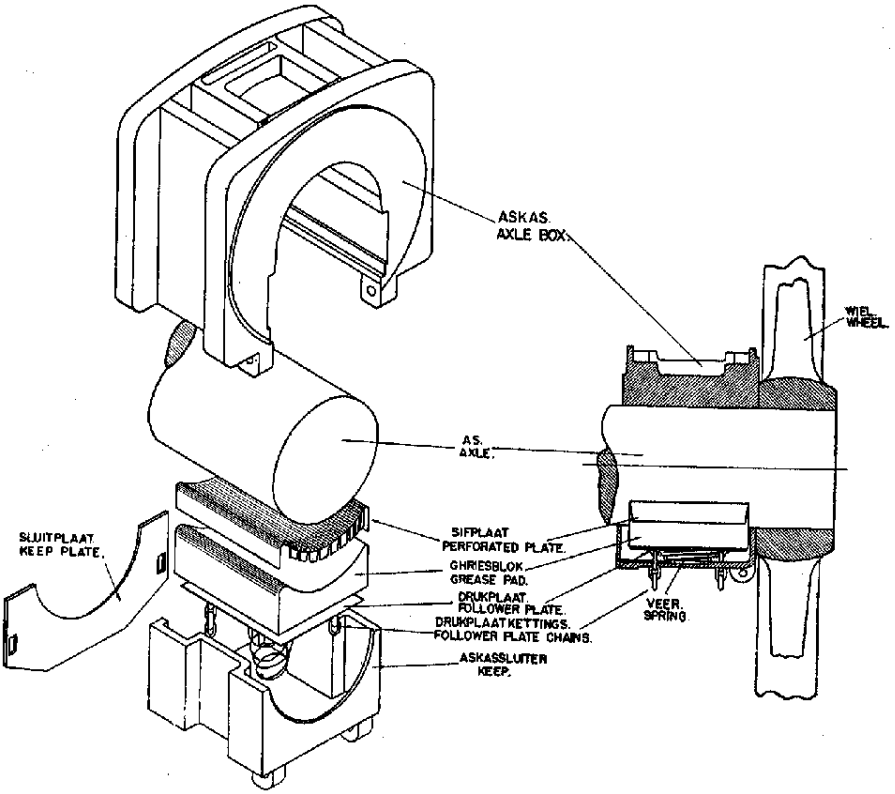


FIG 79 - ARRANGEMENT OF BIG END AND DRIVING BUSHES.
SKETS. 79 - SAMESTELLING VAN GROOTKOP- EN DRYFWIELBUSSE.



SKETS 80 GHRIESASKAS
FIG. 80 GREASE LUBRICATED AXLE BOX

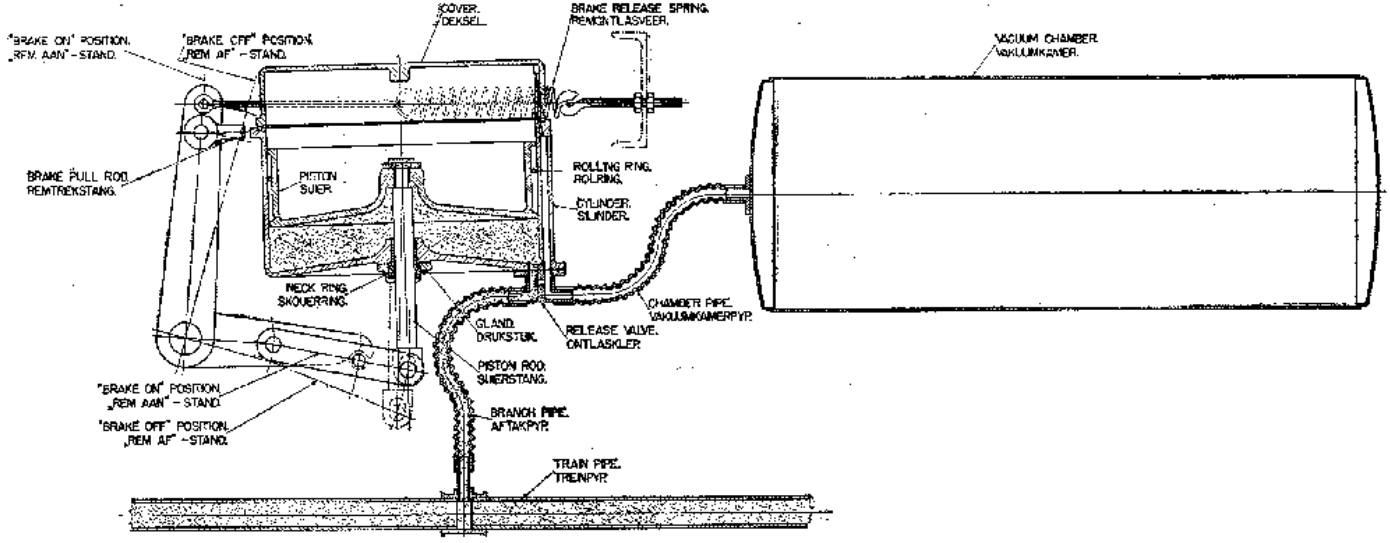
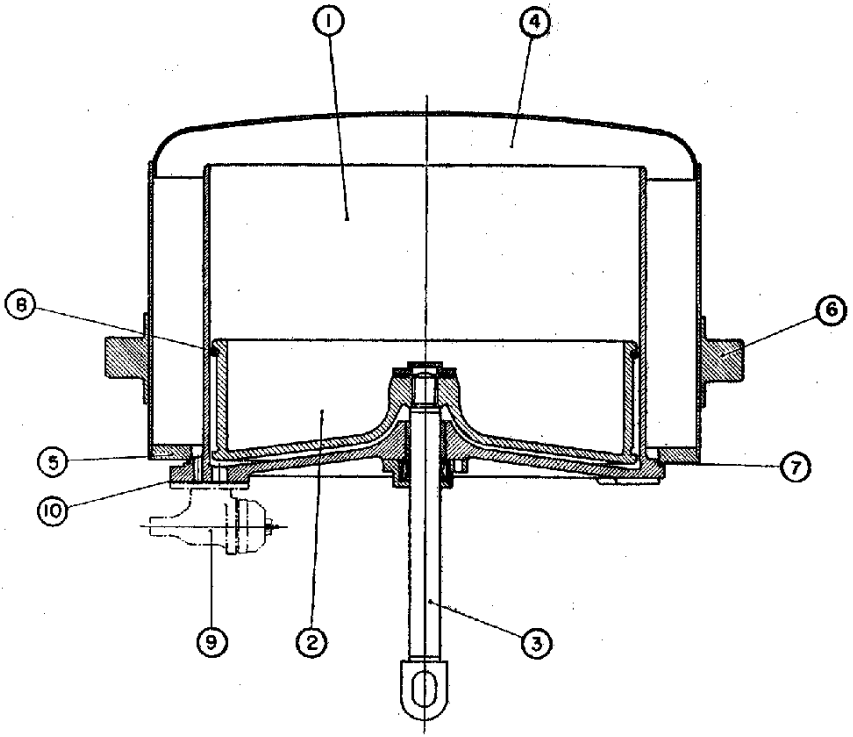


FIG. 81.
SKETS 81.

VACUUM BRAKE SYSTEM – SEPARATE CYLINDER.
VAKUUMREMINRIGTING – AFSONDERLIKE SILINDER.



ITEM	BESKRWING. DESCRIPTION.
1.	SILINDER. CYLINDER
2.	SUIER. PISTON
3.	SUIERSTANG PISTON ROD
4.	SILINDEROMHULSEL CYLINDER CASING
5.	GRONDRING FOUNDATION RING

ITEM	BESKRYWING DESCRIPTION
6.	DRAAGTAP TRUNNION.
7.	VOERING. JOINT RING.
8.	ROL RING ROLLING RING
9.	KOEELKLEP BALL VALVE.
10.	VOEGSEL. JOINTING

SKETS 82. FIG. 82.

SAAMGESTELDE SILINDER.

COMBINED CYLINDER.

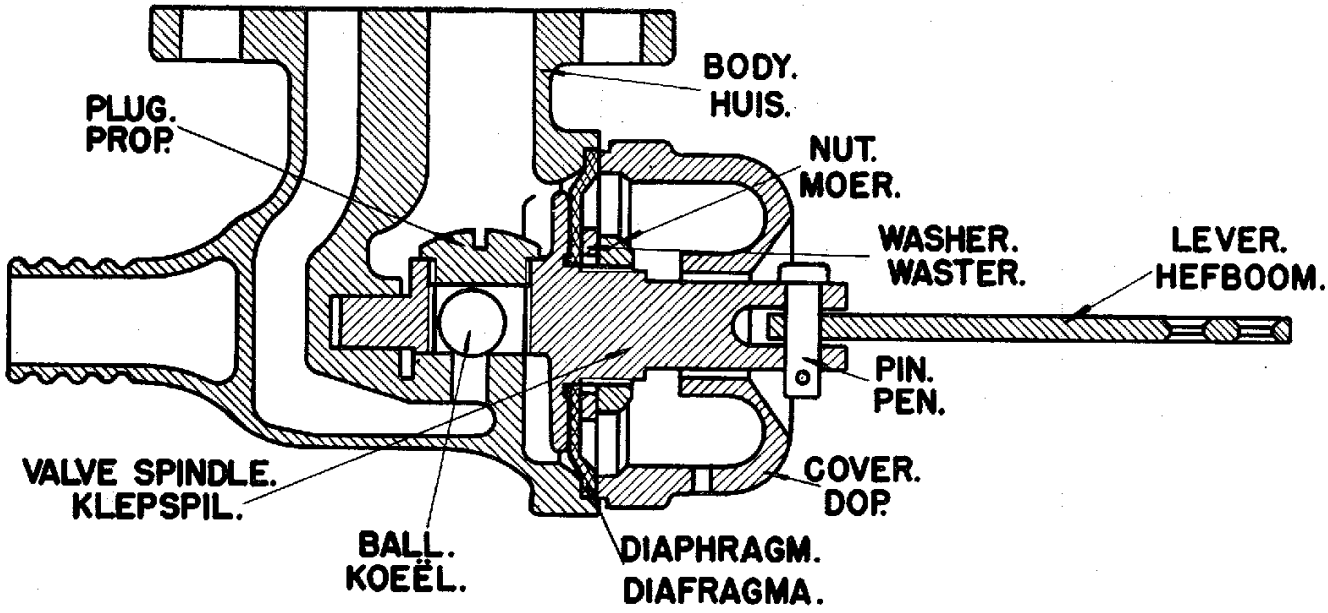
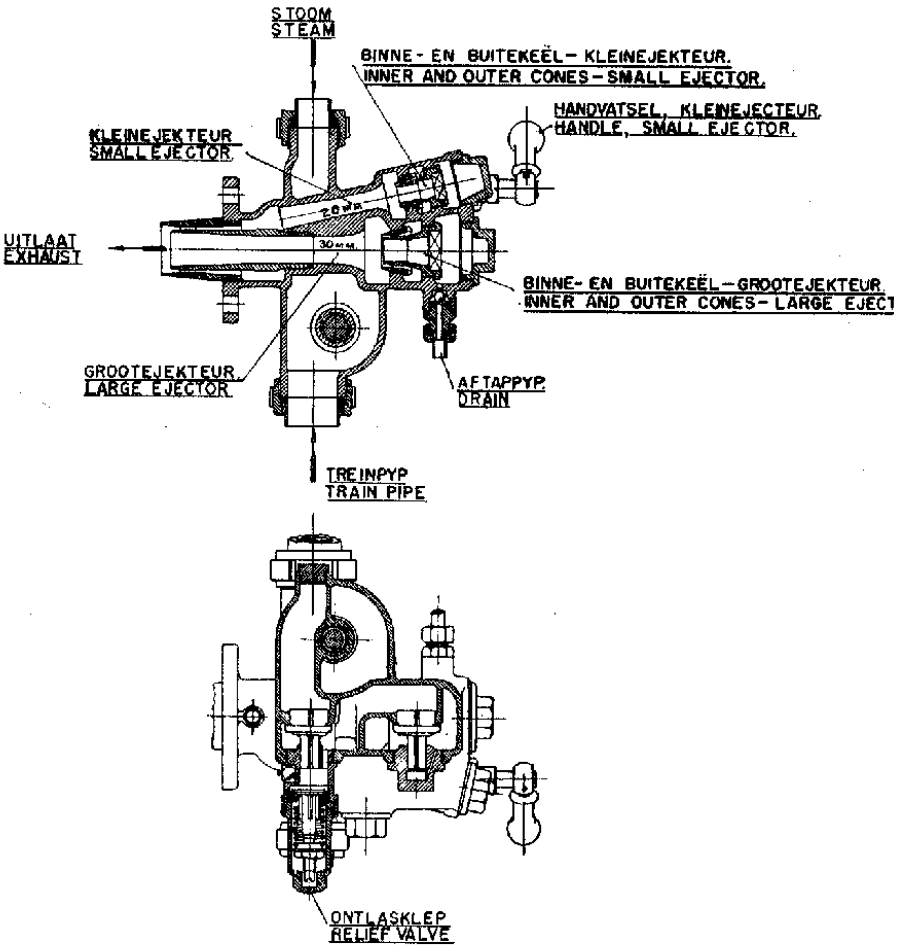


FIG. 83. RELEASE VALVE.
SKETS 83. ONTLASKLEP.



SKETS 84. $^{30}/_{20}$ - DREADNOUGHT-EJEKTEUR.
FIG. 84. "DREADNOUGHT" $^{30}/_{20}$ EJECTOR.

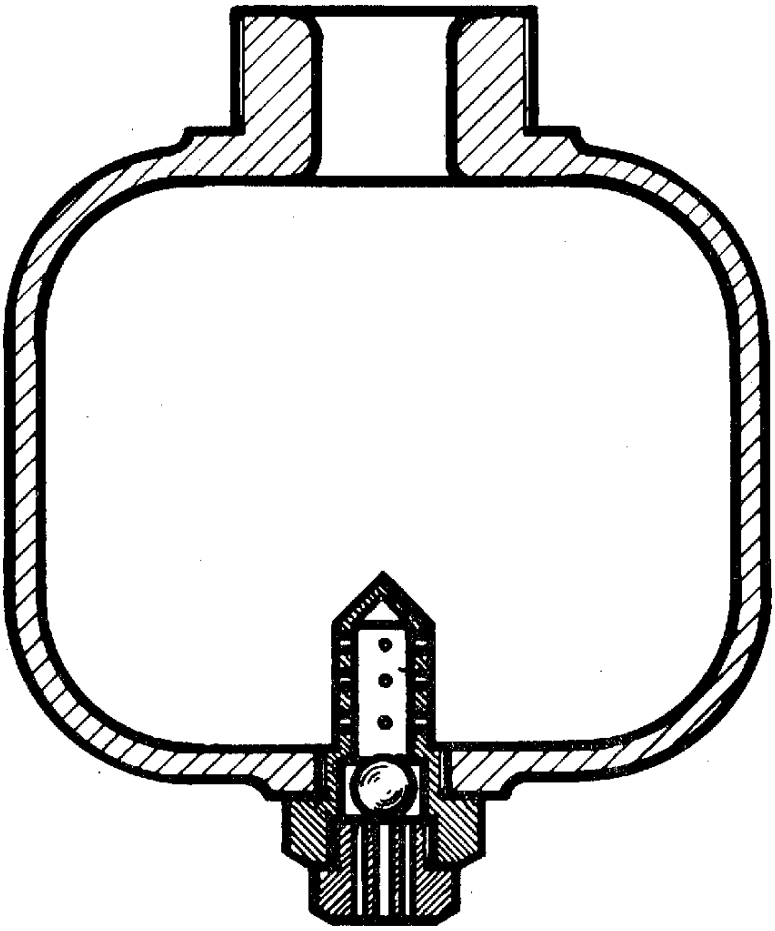
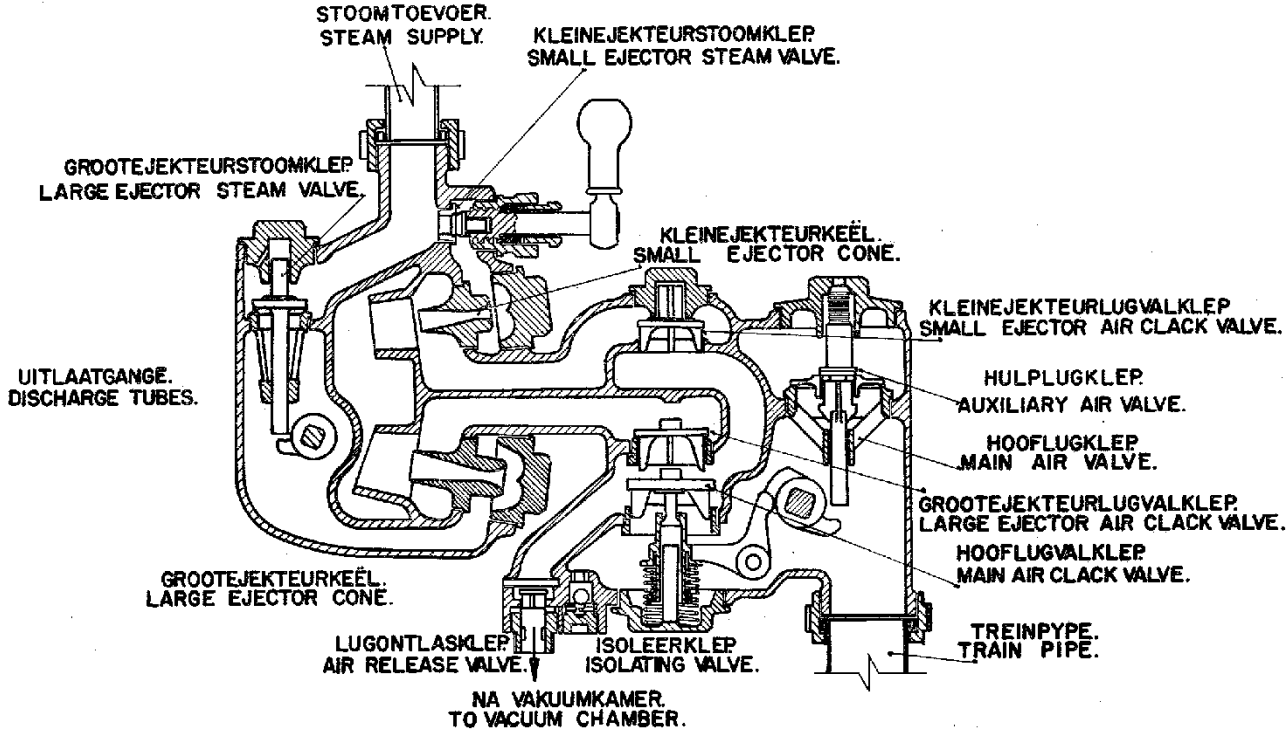


FIG. 85 DRIP TRAP.
SKETS. 85. DRUPVANGER.



SKETS 86. S.J. -EJEKTEUR.
FIG. 86. S.J. EJECTOR.

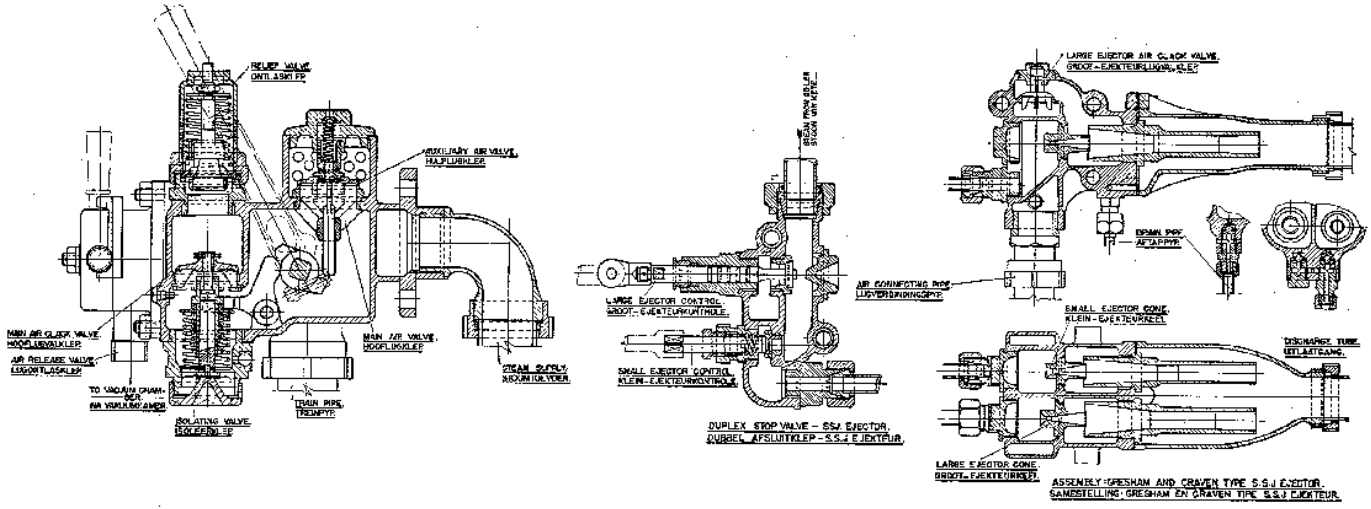


FIG.
SKETS NO. 86A.

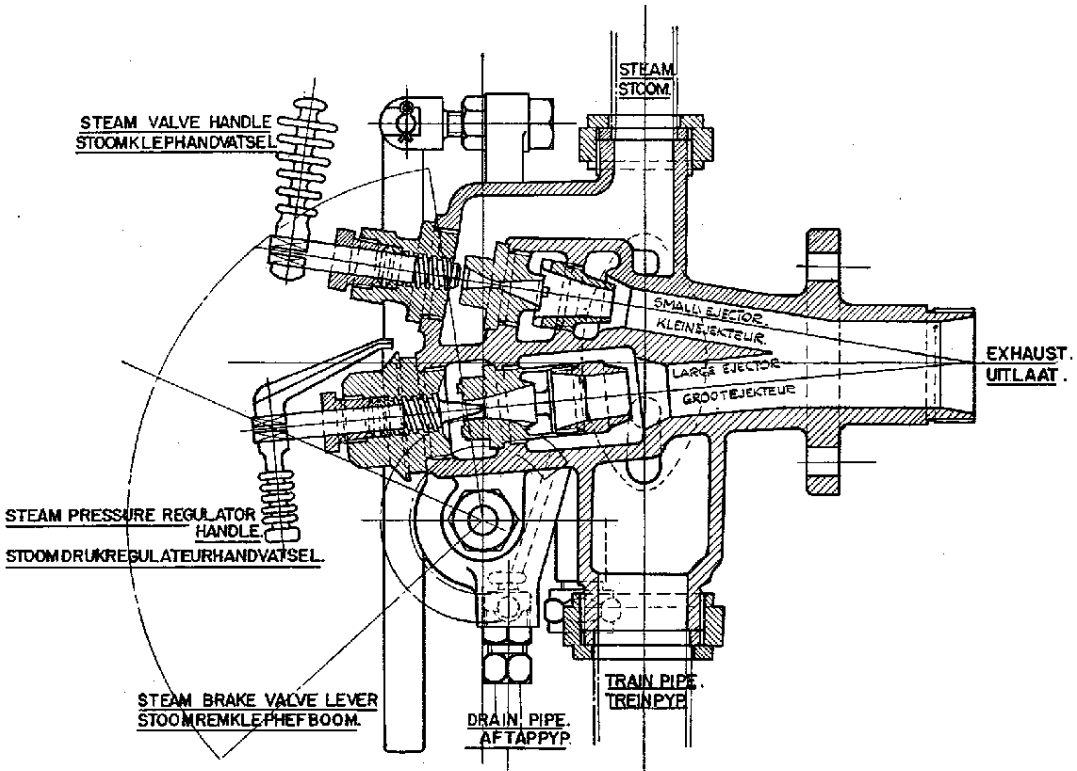
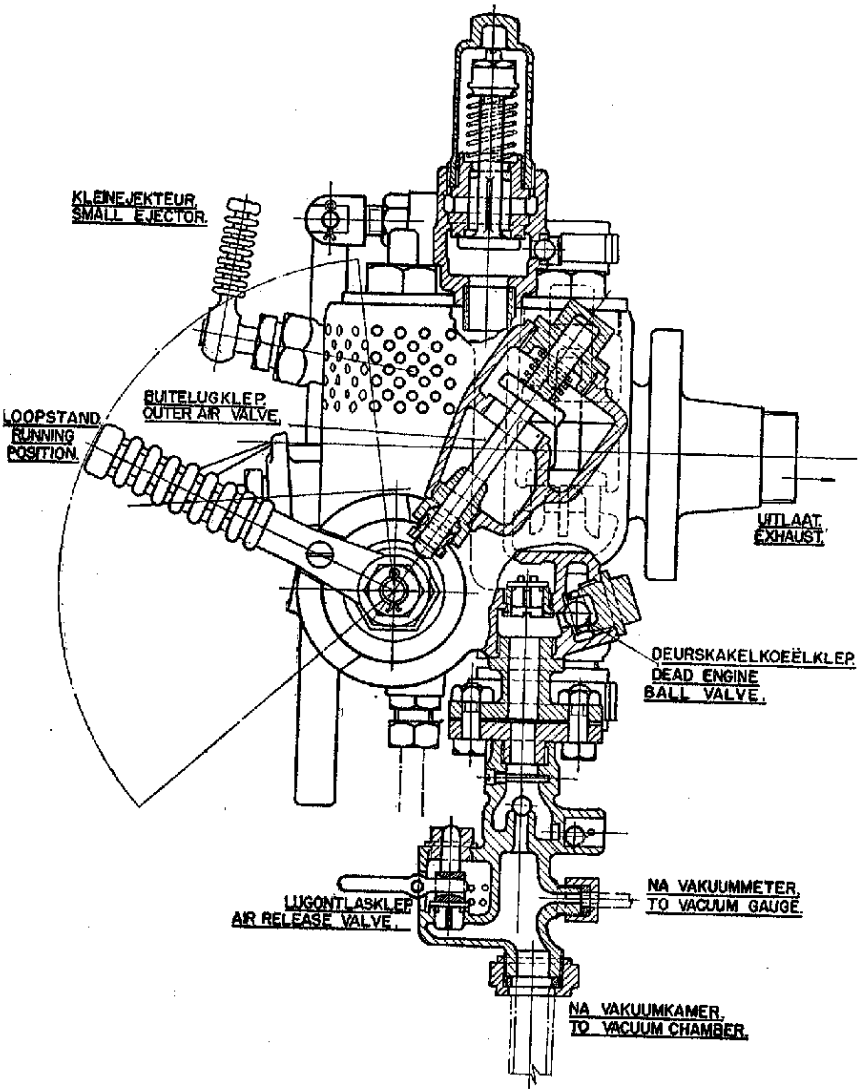
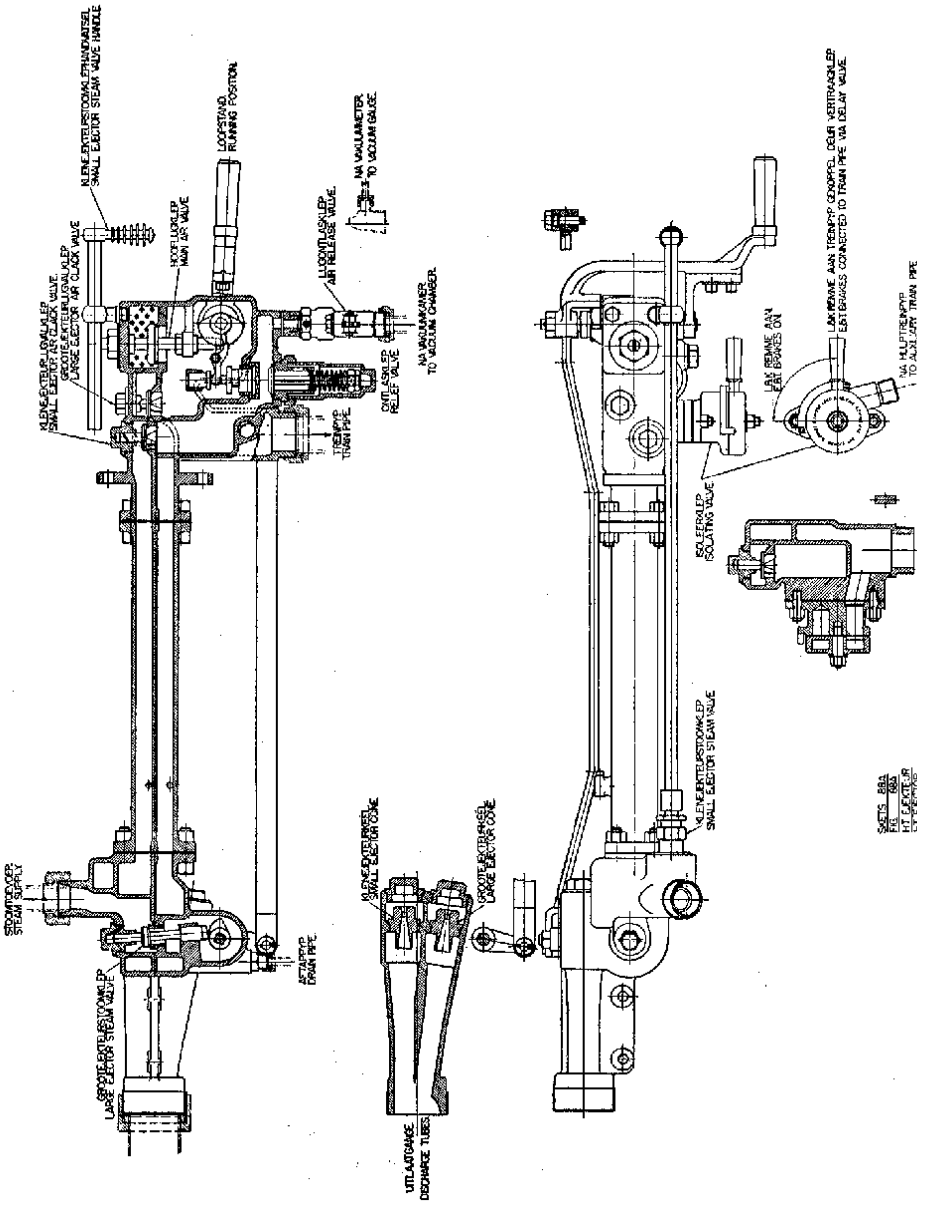


FIG. 87.— ARRANGEMENT OF LARGE AND SMALL EJECTORS.
SKETS — SAMESTELLING VAN GROOT- EN KLEINEJEKTEUR.



SKETS FIG. 88. BUITELUGKLEP EN ONTLASKLEP
OUTER AIR VALVE & RELEASE VALVE.


KLEINE EXTRUSTOOMKLEP SMALL EJECTOR STEAM VALVE
LOOPSTAND RUNNING POSITION
HOOFLUCHTKLEP MAIN AIR VALVE
NA VACUUMMETER TO VACUUM GAUGE
UITLAATKLEP AIR RELEASE VALVE
NA VACUUMKAMER TO VACUUM CHAMBER
KLEINE EXTRUSTOOMKLEP SMALL EJECTOR STEAM VALVE
GROTE EXTRUSTOOMKLEP LARGE EJECTOR STEAM VALVE
KLEINE EXTRUSLUCHTKLEP SMALL EJECTOR AIR CLACK VALVE
GROTE EXTRUSLUCHTKLEP LARGE EJECTOR AIR CLACK VALVE
OVERLAADKLEP RELIEF VALVE
TREINPIJP TRAIN PIPE
STOOMTOEVOER STEAM SUPPLY
AFTAPPIJP DRAIN PIPE
GROTE EXTRUSTOOMKLEP LARGE EJECTOR STEAM VALVE
KLEINE EXTRUSPIJPEN SMALL EJECTOR CONE
GROTE EXTRUSPIJPEN LARGE EJECTOR CONE
UITLAATDRAAD DISCHARGE TUBES
KLEINE EXTRUSTOOMKLEP SMALL EJECTOR STEAM VALVE
ISOLEERKLEP ISOLATING VALVE
LAY REMME VAN LAY BRAKE VAN
LAY REMME AAN TREINPIJP GEKOPPELD, DEUR VERTRAAGKLEP EER BRAKES CONNECTED TO TRAIN PIPE VIA DELAY VALVE
NA HULPTREINPIJP TO AUXILIARY TRAIN PIPE

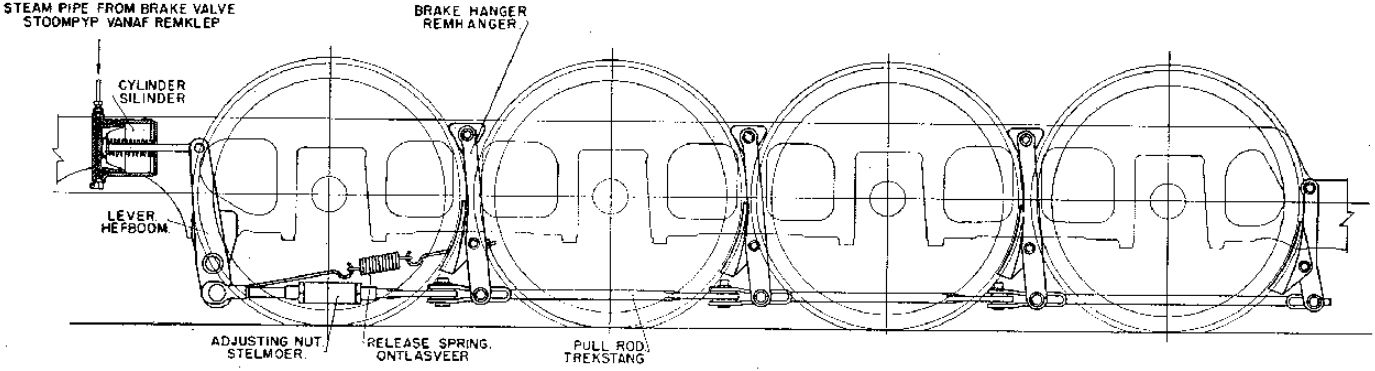
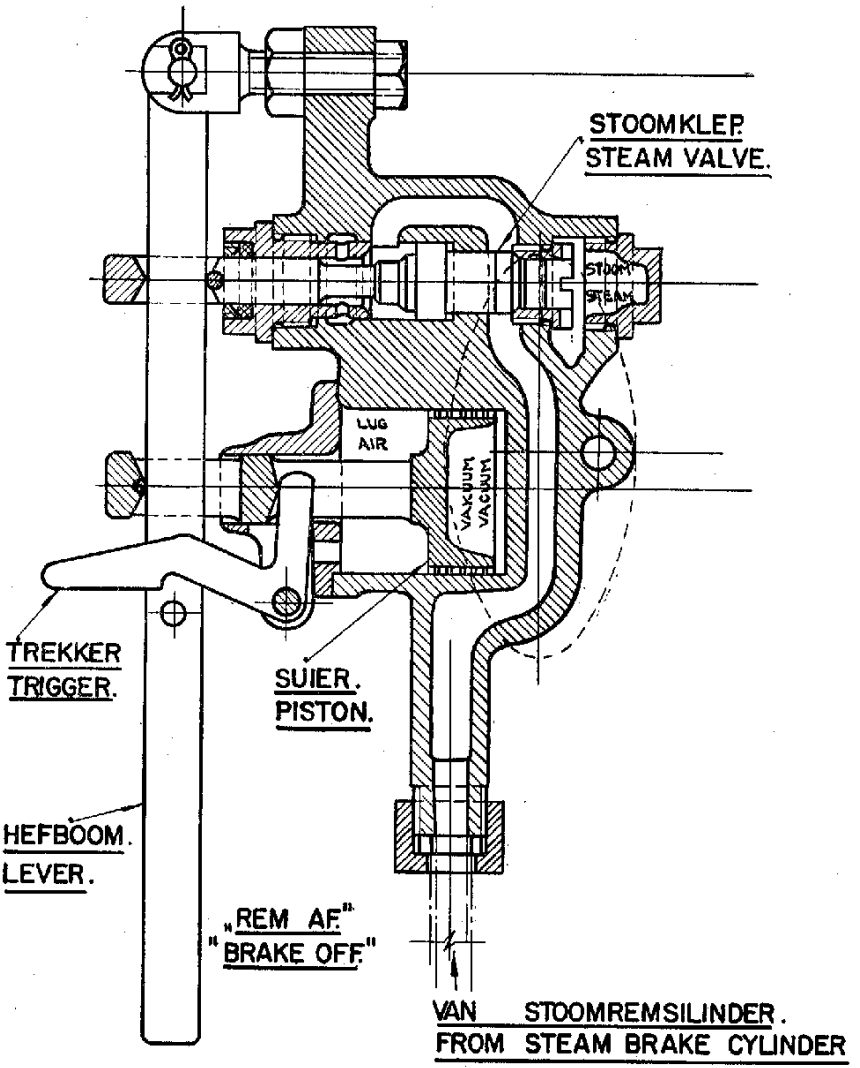


FIG. 89
SKETS. 89.

STEAM BRAKE CYLINDER AND BRAKE GEAR ARRANGEMENT
STOOMREMSILINDER EN REMWERKSAMESTELLING.



SKETS FIG. 90. STOOMREMKLEP. STEAM BRAKE VALVE.

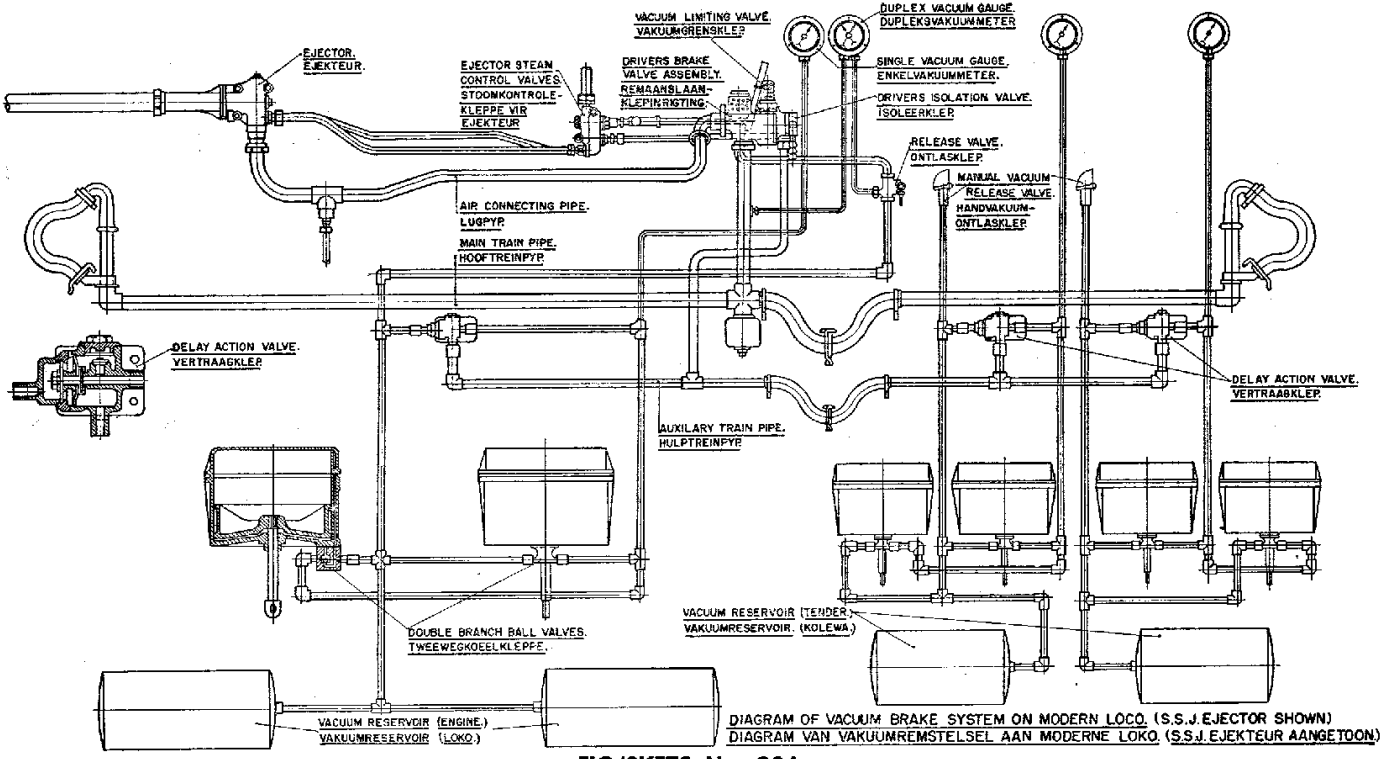


DIAGRAM OF VACUUM BRAKE SYSTEM ON MODERN LOCO. (S.S.J. EJECTOR SHOWN)
DIAGRAM VAN VAKUUMREMSTELSEL AAN MODERNE LOKO. (S.S.J. EJEKTEUR AANGETOON)

FIG./SKETS No. 90A.

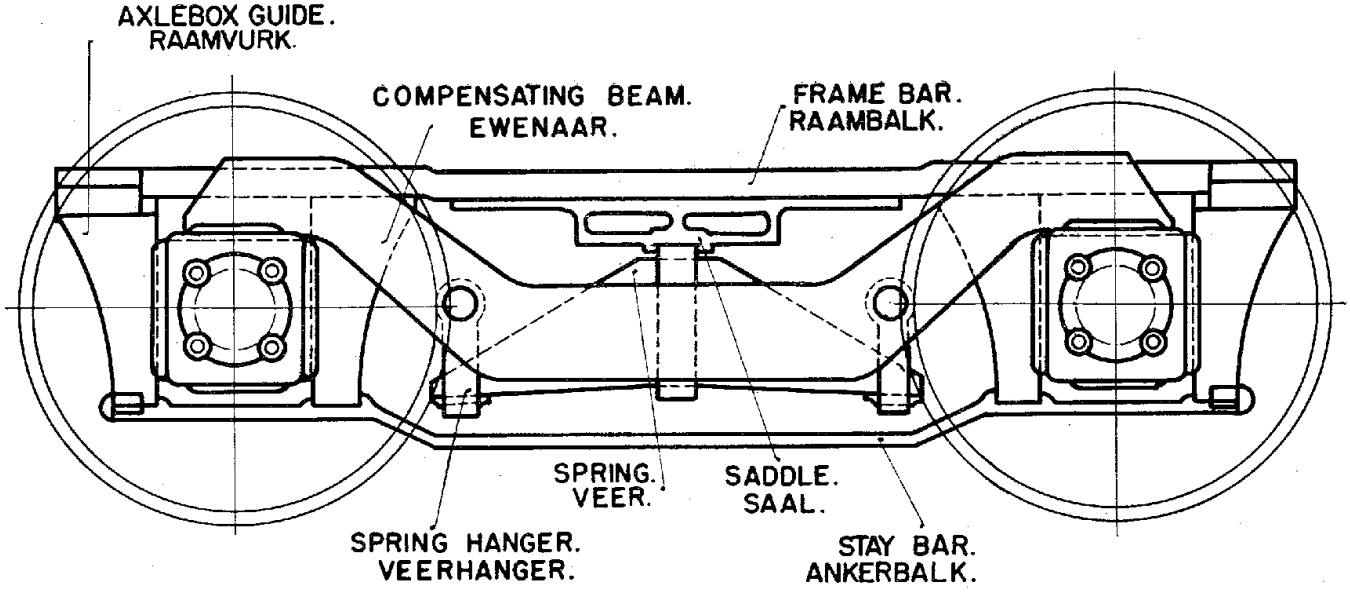
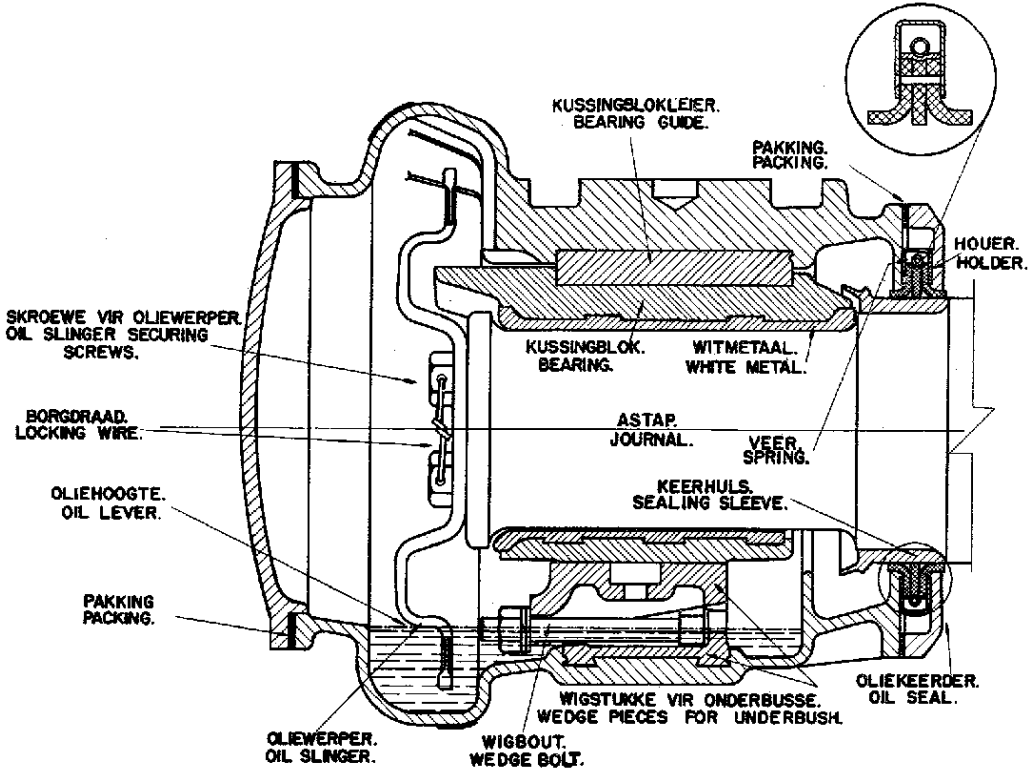


FIG. 91. TENDER BOGIE–BAR FRAME.
SKETS 91. KOLEWADRAAISTEL–BALKRAAM.



SKETS 92. ISOTHERMOS-ASKAS.
FIG.92. ISOTHERMOS TYPE AXLEBOX.

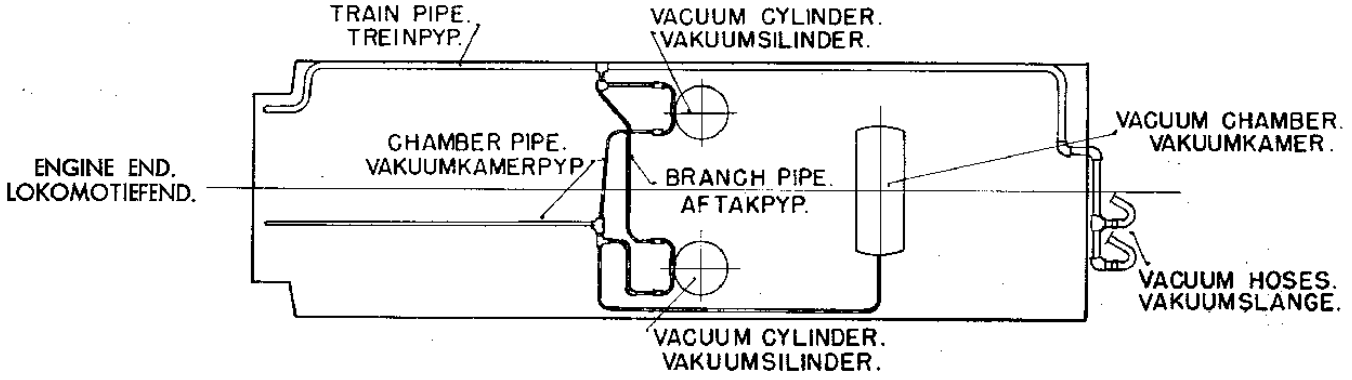
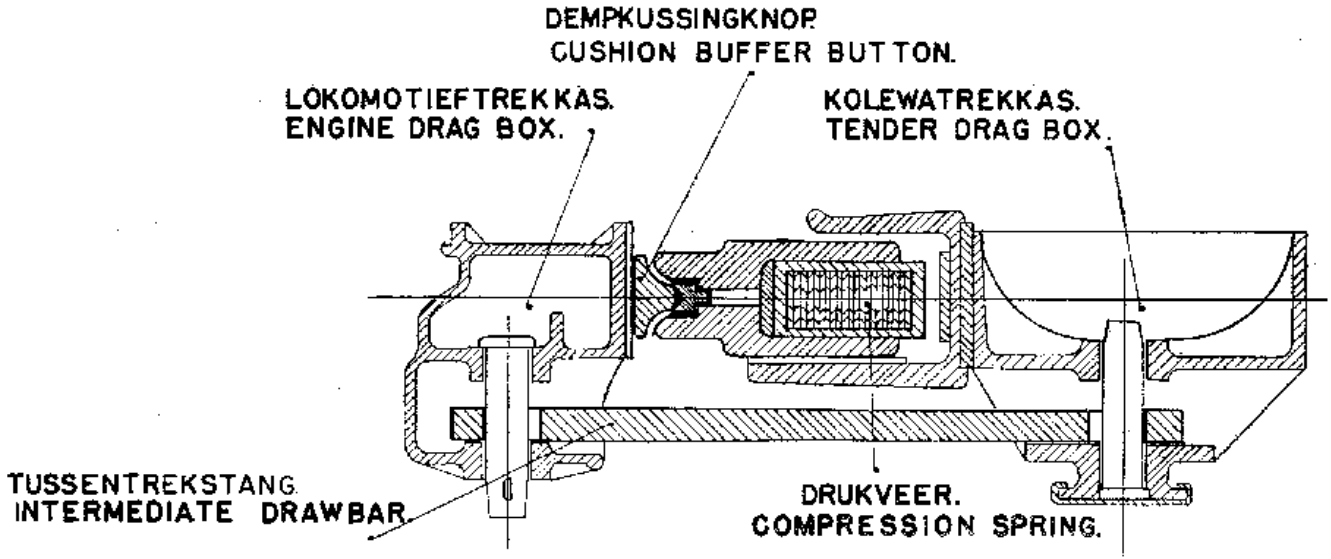


FIG.93. VACUUM BRAKE PIPING ARRANGEMENT ON TENDER.
SKETS 93. VAKUUMREMPYPSAMESTELLING AAN KOLEWA.



SKETS 94 – TUSSENTREKWERK – KLAS 15 F.
FIG. 94 – INTERMEDIATE DRAWGEAR – CLASS 15 F.

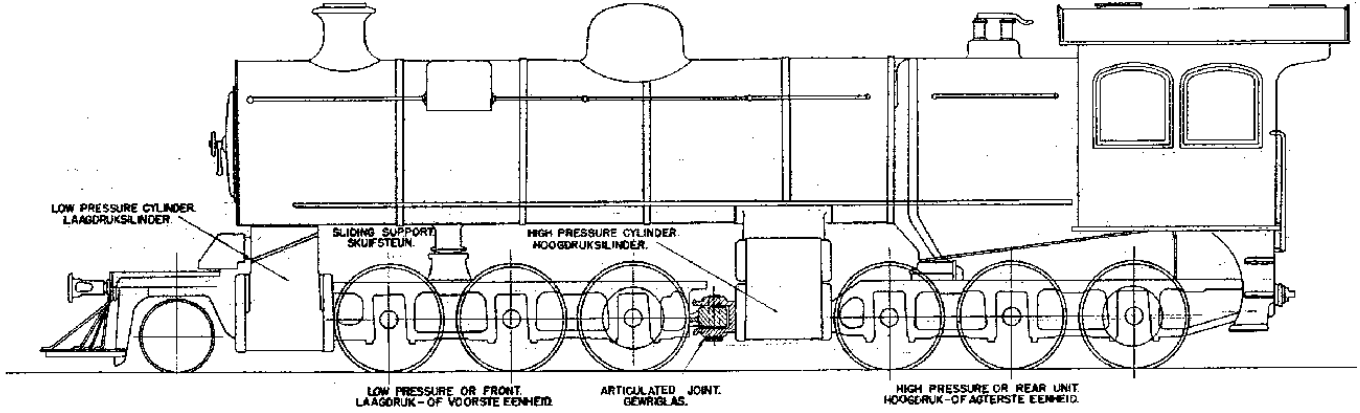
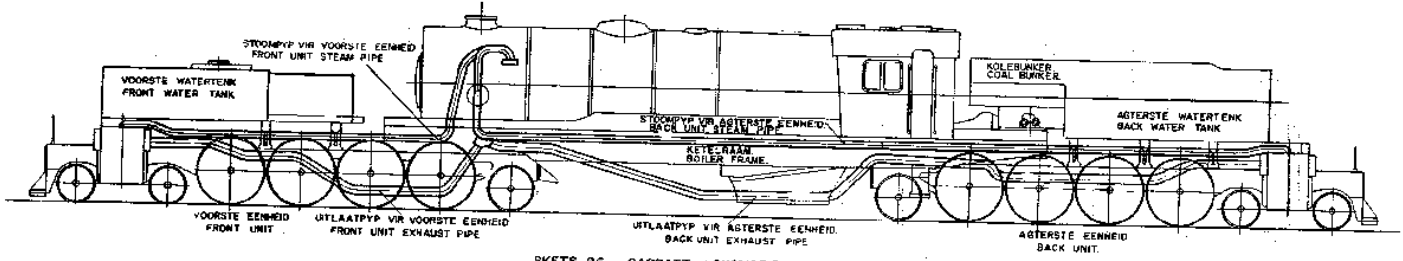


FIG. 95.
SKETS 95.
MALLET COMPOUND LOCOMOTIVE.
MALLET-DUBBELEKSPANSIELOKOMOTIEF.



SKETS 96 GARRATT LOKOMOTIEF.
FIG. 96 GARRATT LOCOMOTIVE.

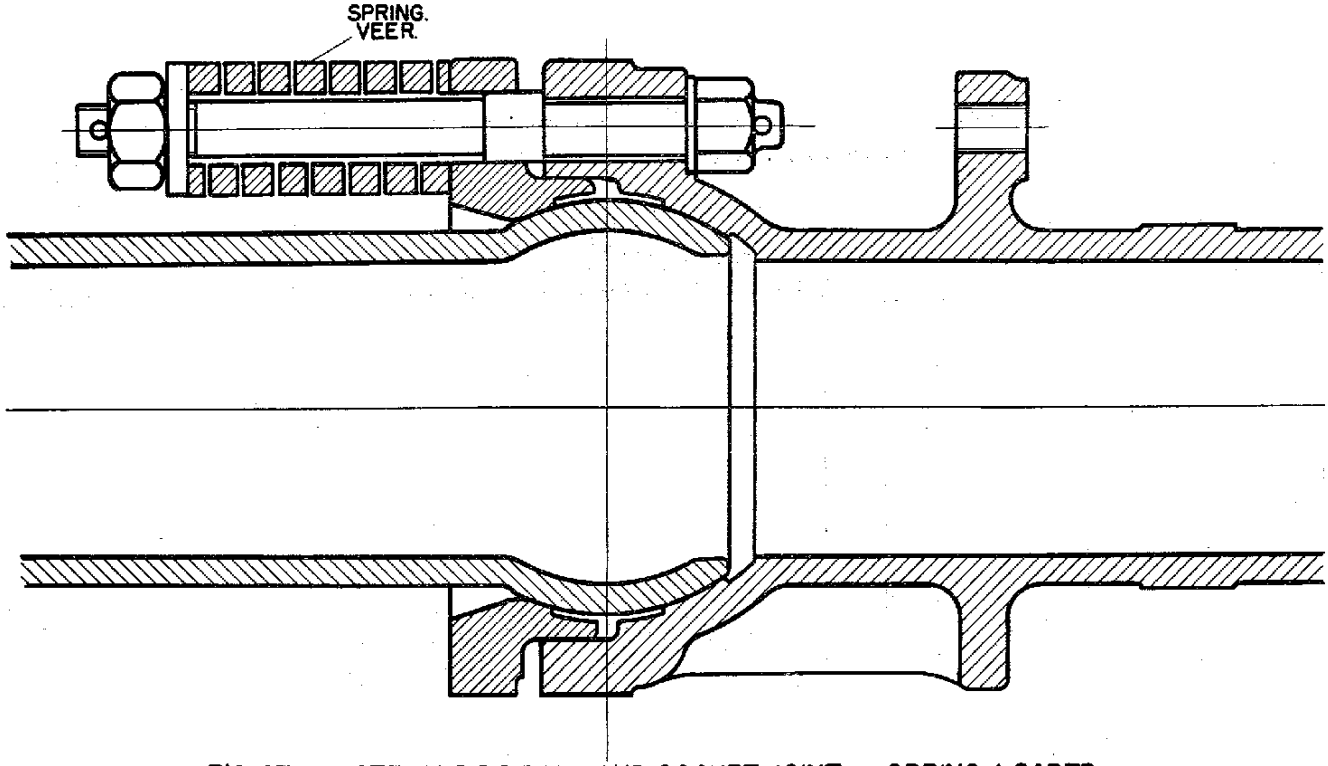
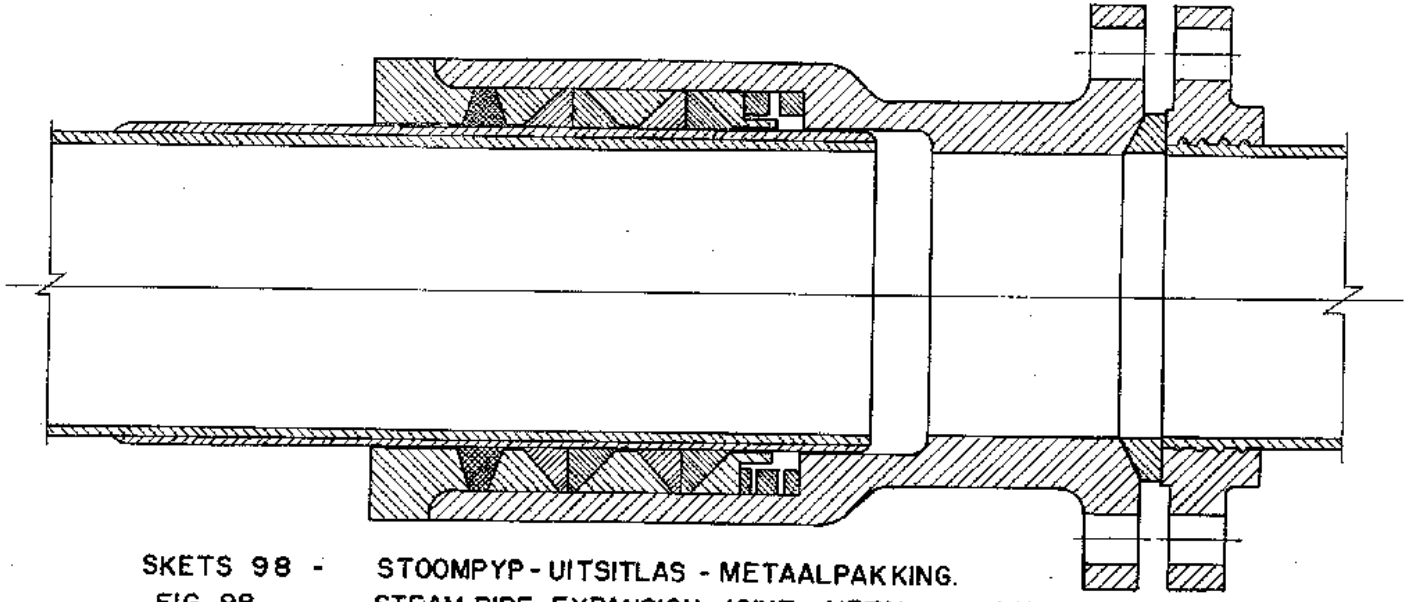


FIG. 97. STEAM PIPE BALL AND SOCKET JOINT—SPRING LOADED.
SKETS. 97 GEVEERDE KOEËLGEWRIG VIR STOOMPYP.



SKETS 98 - STOOMPYP - UITSITLAS - METAALPAKKING.
FIG. 98 - STEAM PIPE EXPANSION JOINT - METALLIC PACKING.

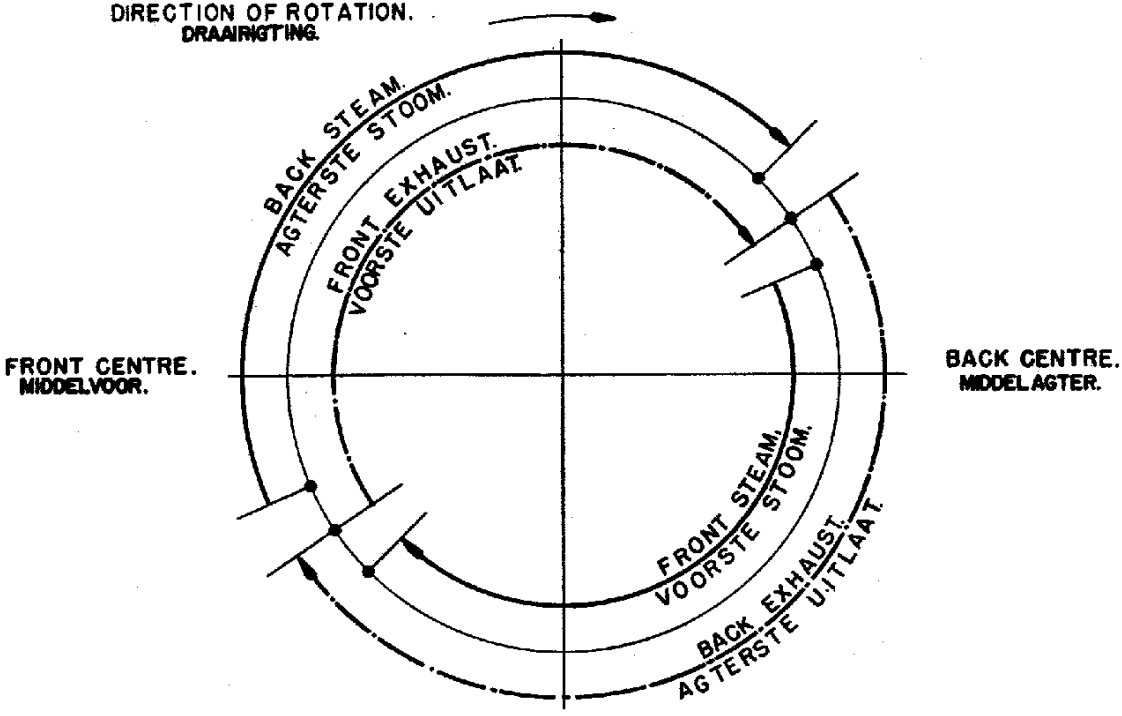
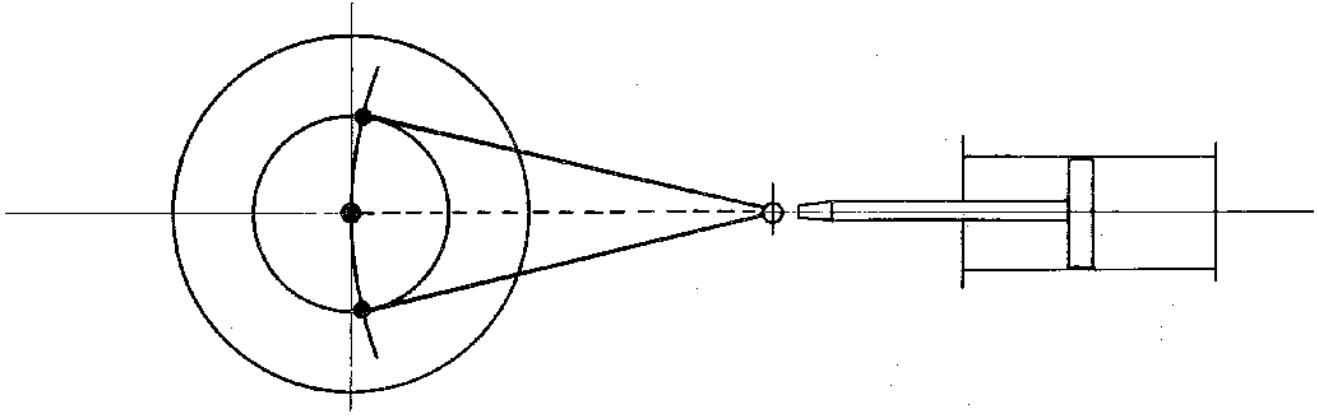


FIG.99. DIAGRAM OF PORT OPENINGS.
SKETS.99. DIAGRAM VAN POORTOPENINGS.



SKETS 100 – DIAGRAM VAN SKUINSSTAND VAN DRYFSTANG.
FIG 100 – DIAGRAM OF OBLIQUITY OF CONNECTING ROD.

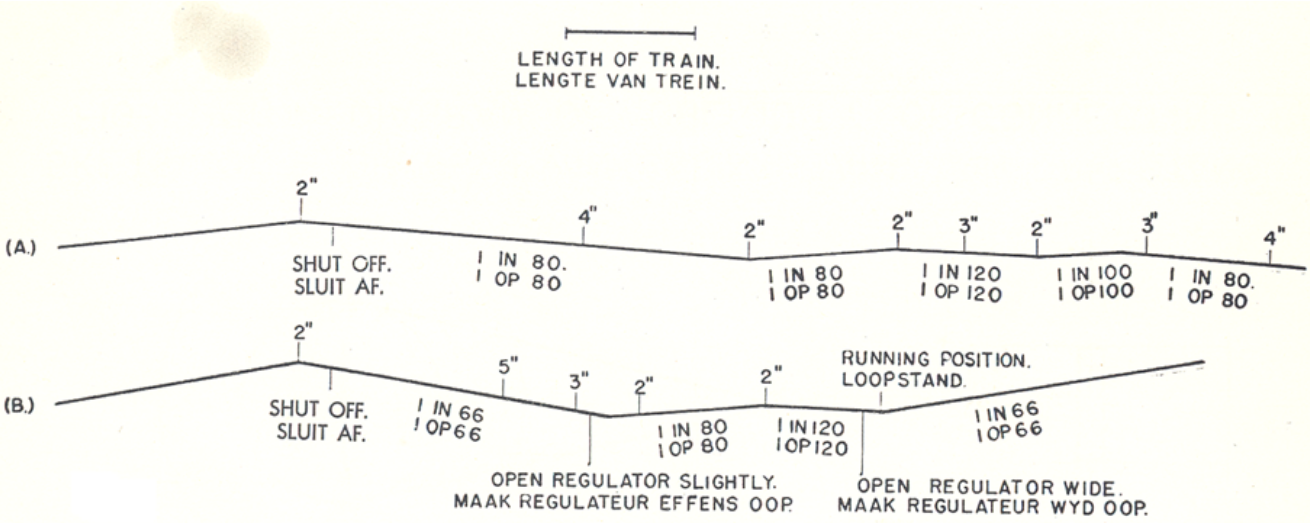


FIG. 101. DIAGRAMS OF SECTIONS OF LINE, SHOWING WHERE, AND HOW MUCH, TO APPLY BRAKES.
SKETS 101. DIAGRAMME VAN AFDELINGS VAN SPOORLYN, AANTONENDE WAAR, EN IN HOE 'N MATE, REMME AANGESLAAN MOET WORD.